

# Corrosion

OFFICIAL PUBLICATION  
NATIONAL ASSOCIATION OF CORROSION ENGINEERS



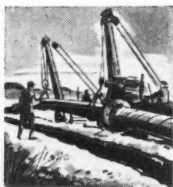
March, 1946

Vol. II No. 1

Pages 1-254

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and

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Kansas City, Missouri

May 7, 8, and 9, 1946

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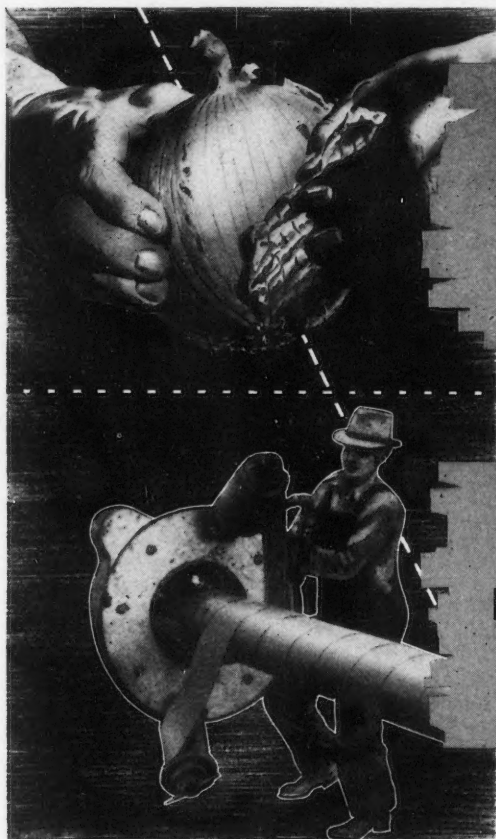
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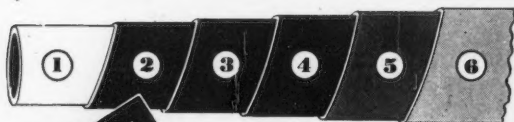
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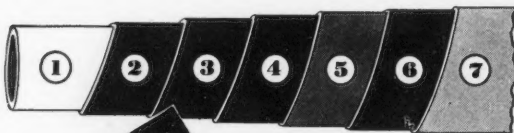
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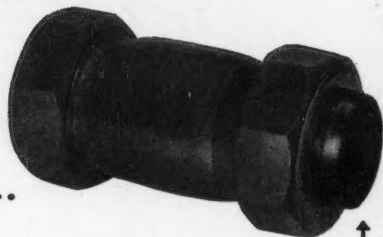
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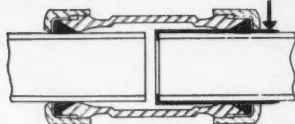
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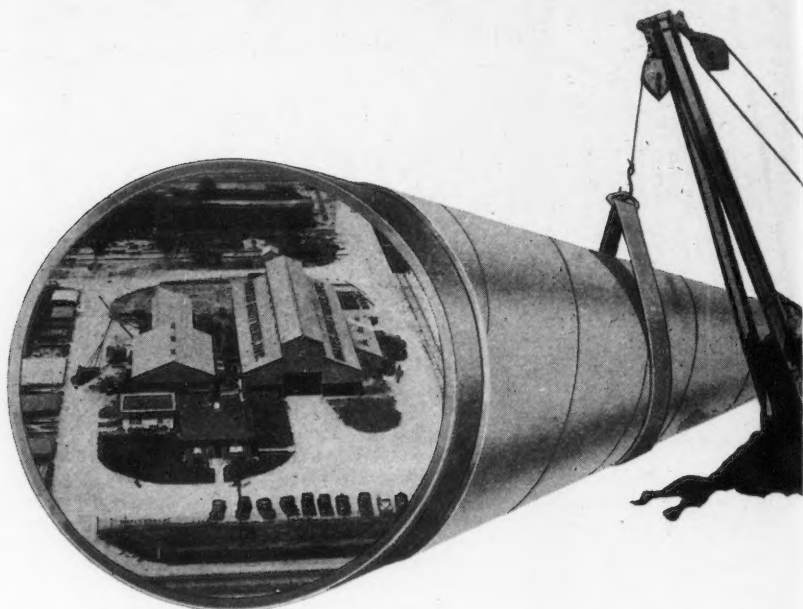


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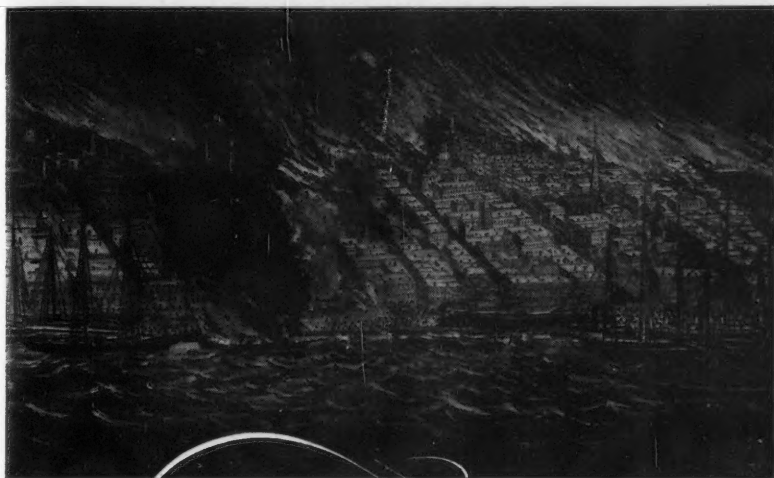
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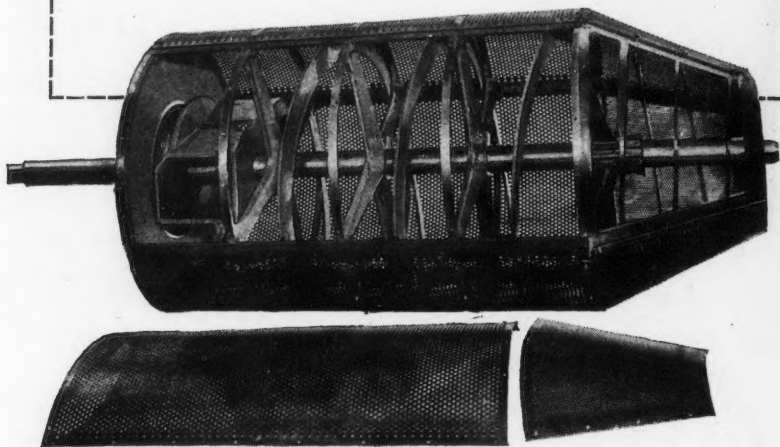
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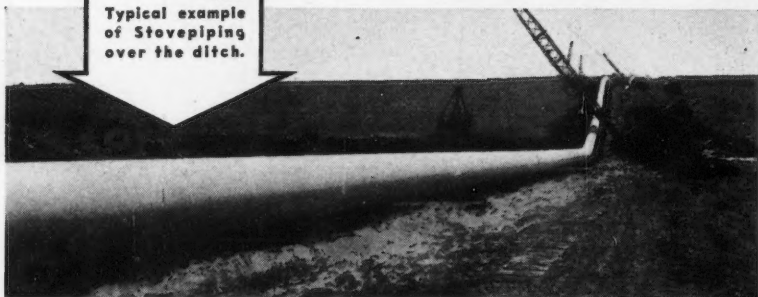
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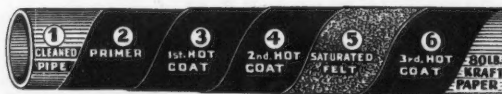
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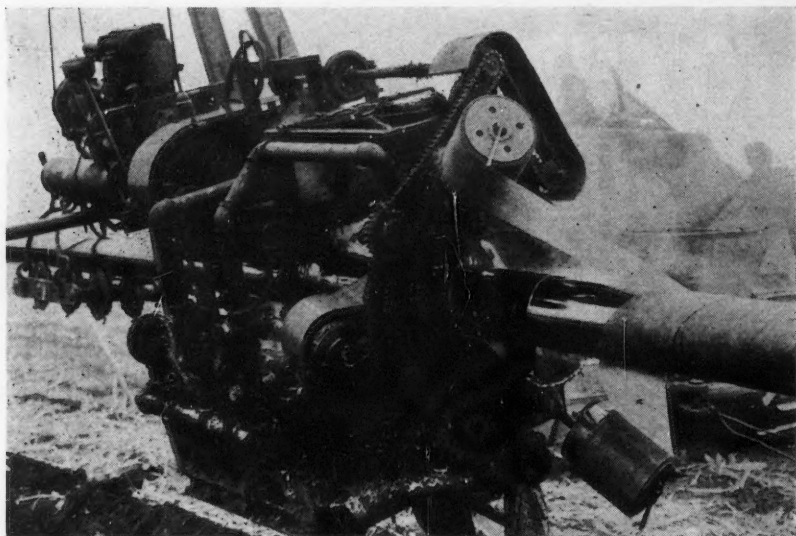
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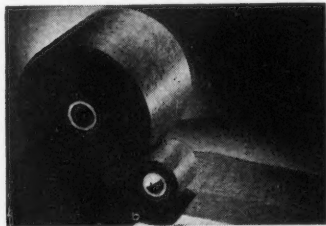
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# Corrosion

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**NATIONAL ASSOCIATION OF  
CORROSION ENGINEERS**

ELTON STERRETT, Executive Secretary

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# Corrosion of Yellow Brass Pipes in Domestic Hot-Water Systems—A Metallographic Study

By **E. P. Polushkin**

Consulting Metallurgical Engineer, Associate Professor of Metallurgy,  
Stevens Institute of Technology, Hoboken, N. J.

and

**Henry L. Shuldener**

Chemical Engineer, President and Technical Director,  
Water Service Laboratories, New York City

**T**HIS PAPER describes the results of microscopic examination of a series of brass pipes removed from apartment and office buildings in New York City, adjacent localities on Long Island, and Philadelphia. They were selected as typical of approximately 400 pipe specimens obtained over a period of five years during an investigation of corrosion in hot-water installations. A part of the investigation is reported in this paper and includes a brief history of the pipes, a description of their inside surface and microstructure, and a study of the effects of corrosion, with particular reference to the structural aspects of local and selective dezincification.

Although the bibliography on the corrosion of brass pipes is quite extensive, it refers almost entirely to corrosion in sea water. The authors believe that their examination of this series of pipes, which had been subjected to the corrosive action of fresh water for various lengths of time, may throw some additional light on the problem of corrosion.

## Pipes Examined

The pipes were made by different manufacturers and their size range from  $\frac{3}{4}$ -inch to 4 inches nominal inside diameter, the majority

being within 1 to 2 inches. They can be divided into two groups according to chemical composition: (1) with a copper content of 60 to 62 per cent and (2) with a copper content of 65 to 68 per cent. The first group (pipes made of Muntz metal) comprises 22 pipes and the second (pipes made of high brass) comprises 18 pipes.

The pipes had been in service in various locations in the hot-water systems of the buildings involved. Some were taken from horizontal lines in the basement, some from overhead distributors and some from vertical risers. The distance, in terms of feet of pipe, of the specimens from the hot-water generator was no less than 75 feet and often 100 to 300 feet. In the majority of cases the water-heating equipment was provided with a regulator to limit the temperature of the hot water supply. The normal range of temperature in pipe systems of this kind is 100° to 160° F.

## Water Supplies

The average chemical composition of the water supplies carried by the pipes is shown in Table I. In evaluating the corrosiveness of a natural water, four factors are considered of prime importance; namely, hard-

TABLE I  
Typical Analysis of Municipal Water Supplies\*

	New York City	Jamaica, L.I.	Rockaway, N.Y.	Philadelphia
Total hardness as CaCO <sub>3</sub> .....	31	70	28	56
Calcium hardness as CaCO <sub>3</sub> .....	15	38	15	34
Magnesium hardness as CaCO <sub>3</sub> .....	16	32	13	22
Total alkalinity as CaCO <sub>3</sub> .....	24	30	9	24
Free carbon dioxide as CO <sub>2</sub> .....	2	12	13	2
Chlorides as Cl.....	2	17	8	5
Sulphates as SO <sub>4</sub> .....	8	40	8	30
Silica as SiO <sub>2</sub> .....	3	13	10	5
pH.....	7.2	6.7	5.9	7.0

\* All figures parts per million except pH.

ness, alkalinity, pH and silica content. The waters listed in Table I are characterized by relatively low hardness, low alkalinity, low pH and low silica content. The waters of lower pH and higher CO<sub>2</sub> content are more corrosive. A characteristic of all of these waters is that they do not deposit a protective mineral coating as do waters with high bicarbonate of lime content, which would be reflected in water analyses as high hardness and high alkalinity. Therefore, the inside surfaces of pipes through which these waters flow are exposed to the corrosive attack of the free oxygen and carbon dioxide dissolved in the water.

The oxygen content of the waters involved was about 80 percent of saturation for atmospheric pressure and the temperature of the cold water entering the hot-water systems.

#### • Lengths of Service of Pipes

The lengths of service of the pipes examined are given in Table II. It should be noted that these figures do not necessarily express the full service life of the pipes because most of the pipes were removed for the purpose of our examination without consideration of whether they were still serviceable. Moreover, some sections of pipe, practically un-

affected by corrosion after relatively long service, are not always typical of the entire piping system of the building. In other words, it was not unusual to find some specimens in a building badly dezincified and other adjacent or near-by sections in sound condition. It should also be noted that the actual service life of the pipes is controlled by local corrosion (plug type), the rate of which is so much more rapid than that of general corrosion that pipe walls are completely pierced before general corrosion has proceeded very far (Table II, pipes 5, 50, 54, 66, 70, 93, 101).

#### Mineral Deposits

The inside surfaces of all pipes were covered with a mineral deposit, which usually had a distinctive color. Below this there was a layer of cuprous oxide (sometimes discontinuous) directly bound with the underlying metal. The cause of this superficial oxidation was of interest, and in order to explain it several new pipes were examined. Only traces of oxide were found on their inside surfaces and further examination of the used pipes proved beyond doubt that the oxide layer had been caused by corrosion during their service.

Surface imperfections such as

TABLE II  
Pipes Examined

Pipe No.	Size of Pipe, In.	Metal	Water Supply	Location of Pipe	Years in Service	Structural Constituents	Grain Size, Microns	Max. Depth General Corrosion, Microns	Tubercles and Plugs
5	1	Muntz metal	New York	Main horizontal feed	10	Alpha and Beta	50	75	Many tubercles. Wall pierced
7H	$\frac{3}{4}$	Muntz metal	New York	Horizontal return	8	Alpha and Beta	50	100	Plugs up to 1000 microns. Many tubercles
9	$\frac{3}{4}$	High brass	New York	Horizontal return	2 $\frac{1}{2}$	Alpha	70	60	Small tubercles
11	1	High brass	New York	Horizontal return	13	Alpha and Beta	70	60	Large tubercle
13	$\frac{3}{4}$	Muntz metal	New York	Horizontal overhead, 32d fl.	8	Alpha and Beta	50	50	Very small tubercles
16	$\frac{1}{2}$	Muntz metal	New York	Vertical riser, 14th fl.	13	Alpha and Beta	50	60	Rows of very small tubercles
17	2	Muntz metal	New York	Vertical branch	13	Alpha Trace	60	.....	.....
24	$\frac{3}{4}$	High brass	New York	Horizontal return	13	Alpha and Beta	60	75	Large and small tubercles
31	1 $\frac{1}{2}$	High brass	New York	Main horizontal feed	2 $\frac{1}{2}$	Alpha	60	215	Many tubercles. Wall pierced.
39	$\frac{3}{4}$	Muntz metal	New York	Main horizontal feed	11	Alpha and Beta	30-50 and larger	400	.....
50	1 $\frac{3}{4}$	High brass	New York	Main horizontal feed	3	Alpha	150-500	100	See text
53	2 $\frac{1}{2}$	High brass	New York	Main horizontal feed	13	Alpha and Beta	150	300	Wall pierced
58	$\frac{3}{4}$	Muntz metal	New York	Horizontal return	12	Alpha and Beta	50	100	Many small tubercles
61	$\frac{3}{4}$	Muntz metal	New York	Horizontal supply	11	Alpha and Beta	120	200	Large tubercles
62	1 $\frac{1}{2}$	Muntz metal	New York	Horizontal return	11	Alpha and Beta	80	50	Small tubercles
65	$\frac{3}{4}$	Muntz metal	New York	Horizontal return	10	Alpha and Beta	170	170	Wall pierced
66	1 $\frac{1}{2}$	High brass	New York	Horizontal supply	12	Alpha	Uneven	100	.....
67	$\frac{3}{4}$	High brass	New York	Horizontal return	11	Alpha and Beta	some 500	150	Wall pierced
73	1 $\frac{1}{2}$	Muntz metal	New York	Horizontal return	11	Alpha and Beta	450	75	Small tubercles
73A	1	Muntz metal	Jamaica	Horizontal return	11	Alpha and Beta	120	210	Badly corroded. Several large tubercles
93	1	High brass	Rockaway	Vertical riser	7	Alpha	80-100	Layer corrosion	Badly corroded. Wall pierced
101	2	High brass	Rockaway	Horizontal overhead	7	Alpha	Av. 100	Layer corrosion	Badly corroded. Wall pierced
104	2	Muntz metal	New York	Horizontal return	16	Alpha and Beta	50	220	Numerous small tubercles
116	1	High brass	New York	Horizontal feed	9	Alpha	70	130	Incipient tubercles
117	3	High brass	New York	Horizontal feed	13	Alpha	100	350 not uniform	Numerous small tubercles
118	1	Muntz metal	New York	Horizontal return	9	Alpha and Beta	50	280	.....
119	1	High brass	New York	Horizontal return	8 $\frac{1}{2}$	Alpha	75	Layer corrosion	.....
120	1 $\frac{1}{2}$	High brass	New York	Horizontal supply	13	Alpha	100	170	Numerous plugs
125	$\frac{3}{4}$	Muntz metal	New York	Horizontal supply	8	Alpha and Beta	50	300	Many incipient tubercles
129	4	Muntz metal	New York	Horizontal overhead	25	Alpha and Beta	50	100 top 340 bottom	.....
132	1 $\frac{1}{2}$	High brass	New York	Horizontal overhead	20	Alpha	100-110	200	Numerous large tubercles
133	1 $\frac{1}{2}$	Muntz metal	New York	Horizontal return	9	Alpha and Beta	60	170	Small tubercles
134B	$\frac{3}{4}$	High brass	Philadelphia	Horizontal branch	9	Alpha and Beta	60	1650	Unusually large tubercles
149	1 $\frac{1}{2}$	Muntz metal	New York	Horizontal branch	7	Alpha and Beta	40	50	.....
156B	1 $\frac{1}{2}$	Muntz metal	New York	Horizontal overhead, 32d fl.	9	Alpha and Beta	70-75	20	Numerous small tubercles
200D	1 $\frac{1}{2}$	High brass	Philadelphia	Horizontal overhead 32d fl.	1 $\frac{1}{2}$	Alpha	175	640	.....
233	$\frac{3}{4}$	Muntz metal	Philadelphia	Horizontal supply	9	Alpha and Beta	.....	.....	Large tubercles

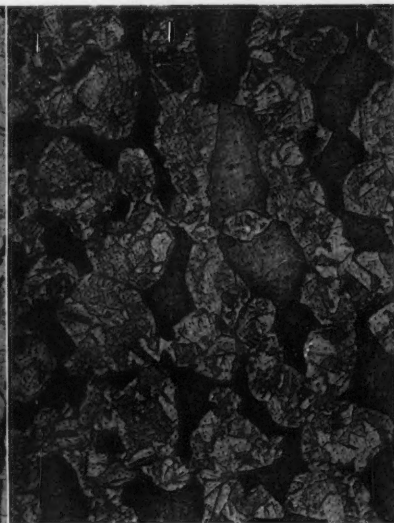


Figure 1

Figure 2

Figures 1 and 2—Muntz Metal.  $\times 200$ .

Figure 1—Longitudinal section, Pipe No. 17.

Figure 2—Cross section, Pipe 73-A.

small cracks, grooves or pits were often found below the mineral deposits. Although some of these defects were insignificant from a general viewpoint, they should be considered a possible cause of incipient corrosion because they can induce it or accelerate its action.

In some pipes the oxide layer was not found, but the metal was covered with a grayish black film, which protected the metal from oxidation (pipes 61 and 65). This was evident from the condition of bare spots, which had been attacked by corrosion where the film had been broken off. This film might have been formed during the manufacture of the pipe or in the early stage of service, as the result of water action.

A few unsuccessful attempts were made to determine mineralogical

composition of the deposits. They all failed because not enough powder could be scraped from the pipe surface.

#### Microstructure of Pipes

Specimens for microscopic examination were usually polished in two perpendicular sections, longitudinal and transverse, but for examination of advanced corrosion at the root of plugs, a tangential section (parallel to geometrical axis of pipe) was also prepared. The specimens were examined before and after etching. Two etching reagents were generally used: (1) ammonium hydroxide with addition of a few drops of hydrogen peroxide and (2) aqueous solution of ammonium persulphate. In the routine etchings of alpha-beta brass it was sufficient to bring out the two constituents, but in some



cases, where the structural peculiarities of alpha grains required development, a deeper etching with the same reagents was applied.

Polished sections containing large accumulations of metallic copper required a special etching method. Small droplets of ammonium persulphate solution were placed at different points within the area of the copper deposit, one after another at certain intervals, so that the time of etching was different at these points. After the reagent had been washed off and the specimen dried, the etched spots were examined and compared. In this manner a proper degree of etching was determined without a repeated repolishing and re-etching of the whole section. This method was used for examination of microstructure of the copper deposits that had been formed by corrosion.

The distinctive features of the microstructure of the pipes were directly related to their chemical composition and conditions of processing. Twenty-two pipes were made of Muntz metal and 18 of high brass. The first alloy contains two solid solutions, alpha and beta; the second, only alpha. The proportion of beta in pipes made of Muntz metal varied according to the zinc content, which in industrial alloys of this type ranges from 37 to 41 percent, and, to a certain extent, according to the rate of cooling from the temperature of the last operation of hot work. In some pipes of the alpha-beta group (16, 17, 39, 67, 118 and 113) the amount of beta was found to be considerably below the normal proportion. For the same reasons a trace of beta was found

in one pipe of the alpha group (No. 24).

Typical views of the microstructure of alpha-beta brass pipes are shown in Figures 1 and 2, which represent, respectively, longitudinal and transverse sections of pipes 17 and 73A. In both photomicrographs beta appears dark. Although both pipes were made of Muntz metal, the difference in the amount of beta is very pronounced.

The following deviations from the normal structure were found occasionally:

1. Coarse primary structure, not entirely eliminated by annealing, as evidenced by Widmannstätten pattern of alpha and beta arrangement.
2. Striking variations in grain size (Figure 3).

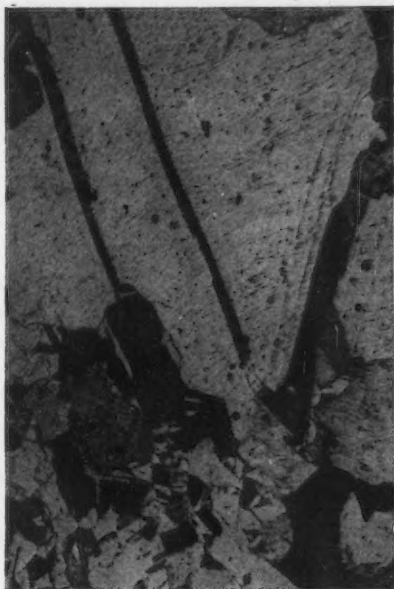


Figure 3—Inhomogeneous grains of alpha, pipe No. 66.  $\times 200$ .

3. Distorted shape of grains and presence of slip bands, which indicate insufficient annealing.

4. Inhomogeneous distribution of beta.

These defects were not common, but are mentioned only for a better understanding of all the conditions that may promote or influence corrosion.

Grain size was determined by measuring the diameter of major sections of grains by means of a micrometer eyepiece, and also by the direct comparison of the grain size with the standard photomicrographs of American Society for Testing Materials. The values of grain size in microns are shown in Table II.

As shown in this table, 15 pipes had the smallest grain size of 50 microns; in the majority of pipes (28) it was from 50 to 80 microns; in 10 pipes, from 100 to 200 microns, and in two pipes, from 450 to 500 microns. One of the last two pipes had Widmannstätten structure and the other had exaggerated grain growth.

These figures of grain size should be divided by 2 if it is desired to compare them with the mean values of grain size as usually determined by the ordinary method.

#### Definition of Terms

The term *general corrosion* is taken to mean the corrosion of the whole inside surface of the pipe, or at least a large part of it.

*Local corrosion*—i.e., *plug-type corrosion*—refers to a destructive attack concentrated at a specific point only, the rest of the surface remaining intact or being attacked at a much lower rate.

Other terms mentioned in this paper in connection with corrosion are defined for the sake of clarity, as follows:

*"Layer-type" corrosion* refers to a copper deposit that extends over a large area and shows stratification and porosity of the kind generally found in the plug type. It may be considered as a plug extended over a large area. Often corrosion advances so rapidly at some points in the layer that typical semicircular plugs are developed, which penetrate into the wall of the pipe.

In all three terms, the meaning of "corrosion" includes the entire cycle of processes of corrosion; viz., dezincification as well as subsequent oxidation of copper.

*Selective dezincification* refers to a process of which a singular feature is the selective removal of zinc from the alpha or beta constituents.

*Preferential attack* is used to designate the order of destruction of structural constituents. In alpha-beta brass pipes, beta is always corroded first. Another instance of preferential attack is found in old bronzes, where either alpha or eutectoid is attacked first.<sup>20</sup>

Microscopic examination showed that all pipes examined had been attacked by general corrosion, the difference between individual specimens being only in the depth of penetration. It was also revealed that the process of corrosion in alpha-brass pipes had advanced in two steps: first, alpha was destroyed and replaced by metallic copper, then the copper was oxidized. Examination of longitudinal and transverse sections indicated that at the advanced line of corrosion little or no cuprous oxide was found. How-

ever, as the inside surface of the pipe was approached an increasing amount of cuprous oxide was found, but almost no copper. Since a layer of cuprous oxide was always found below the mineral deposit, we must conclude that it was the last product of corrosion.

A second layer of more recent origin, at the advance line of corrosion in contact with the normal structure, consisted of copper and cuprous oxide. In one pipe (No. 11) copper deposit was not found; there was only oxide and alpha. However, it seems likely that the absence of metallic copper was due to rapid oxidation of the copper into oxide, as soon as it had been formed.

General corrosion of the constituents in alpha-beta brass pipes also took place in two steps, as described above, but its distinctive feature was in the preferential attack of beta. In extreme cases, as in pipe 54, beta was destroyed throughout the whole thickness of the wall while alpha remained completely unaffected. On the other hand, in some pipes the lag between the attacks on beta and on alpha was short.

The depth of general corrosion was determined on longitudinal or transverse sections of pipes by direct measurement under the microscope. The values of depths given in Table II represent the maximum penetration of corrosion, which is the sum of the maximum widths of both layers; i.e., (1) cuprous oxide alone and (2) cuprous oxide plus metallic copper. In alpha-beta brass pipes these figures give the maximum depths of preferential attack on beta.

As the pipes were in service for

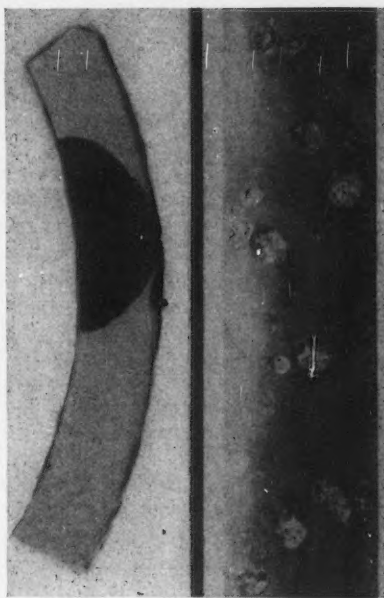


Figure 4

Figure 4—Plug in pipe 66.  $\times 3$ .

Figure 5—Tubercles in pipe 5. Natural size.

different periods of time, the only possible way of comparing the rates of their general corrosion was on the basis of mean values of the depths of corrosion per year. Table II shows that the rate was very slow in a great majority of the pipes. Of 32 pipes in which the depth of penetration was determined, the rate was  $1/40$  mm. per year in 23 and  $1/40$  to  $1/20$  mm. in 5. Only in one pipe was it slightly over  $1/2$  mm. per year. This pipe (200D) was from Philadelphia and in one year of service developed general corrosion 540 microns deep. Table II also indicates that there is no relation between grain size and the depth of corrosion.

### Local Corrosion

The destructive action of this type of corrosion is concentrated on a single point of the surface, which is vigorously attacked. As in general corrosion, the process involves removal of zinc and formation of a copper deposit, which then becomes partially oxidized. A large local accumulation of copper in the pipe wall is commonly called a "plug," as it often extends through the entire wall thickness (Figure 4). The mound built up by the products of corrosion on the inside surface of pipe above the plug is generally referred to as a "tubercle" (Figure 5).

Three types of plugs were found in brass pipes: (1) with all the original metal dezincified, (2) with only beta dezincified and alpha intact, and (3) plugs similar to the first type but which had developed from a layer of corrosive products (Figure 6). An ordinary plug, type 1, can be distinguished easily from the normal metal by visual examination of the pipe, whereas a plug of type 2 appears only slightly different from the surrounding metal, even in a finely polished section of the wall. The third type represents merely an advanced stage in the layer corrosion.

Local corrosion was very common in the brass pipes examined, both alpha and alpha-beta brass being susceptible to that kind of attack. The number of large tubercles found in badly corroded pipes was as high as 20 in a 3-inch length of pipe and their size sometimes reached 13/16-inch in length and 1/2 inch in height.

All plugs of types 1 and 3 consisted of porous accumulations of

copper mixed with some mineral products of corrosion. Figures 6 and 7 show sectional views of two plugs, which display dark and light concentric zones. Microscopic examination proved that the difference between the zones was mainly in the number and size of holes. In the dark zones porosity was greater and the holes were larger. The alternate arrangement of zones indicates a certain periodicity of the corrosion process. Apparently, the infiltration of a corrosive liquid through the spongy copper had been going on continuously, but with different intensities, and the dark zones were formed during the most vigorous periods of corrosion, when even a part of the copper had been removed.

The outlets of plugs on two sides of the pipe wall were usually opposite each other, but in pipe 125 the wall was pierced in an oblique direction, and the visual examination of the tangential section of the wall revealed a considerable extension of the plug along the pipe length.

Microscopic examination of tubercles disclosed that they had been built up of concentric shells, which usually had different colors and often were separated by empty spaces. In a tubercle of pipe 16 the colors of shells were white and pink, and the center was hollow. The tubercles frequently had a central cavity, apparently caused by the evolution of a gas.

The size of the tubercles was sometimes disproportionately small in comparison with the size of the underlying plugs. It is evident, therefore, that some of the products

were carried away by the water flow.

The chemical composition of tubercles is given in Table III. The analyses were made on tubercles removed from pipes 125, 134B, 196 and 247. (The last two are not included in the list of pipes examined.) The prevailing components are zinc, combined water and carbon dioxide.

The layer type of corrosion was found in three pipes (73A, 93 and 101) removed from buildings in localities where the water is more corrosive than in New York City. The structural characteristics of these copper deposits—porosity and stratification—are the same as in the plug type of deposits.

The origin of local corrosion is still a mystery. In boiler tubes it has

TABLE III  
Analysis of Tubercles

Pipe No.	Water Supply	Alloy	Combined Water and CO <sub>2</sub>	COMPOSITION—Percent			
				Zn	Cu	Fe	SiO <sub>2</sub>
125	New York.....	α and β	24.1*	51.7	1.7	1.7	5.3
134B	Philadelphia.....	α	27.8	52.1	1.6	1.2	1.6
196	New York.....	α and β	26.7	53.5	1.9	1.8	2.0
247	New York.....	α	23.8	51.8	0.6	1.8	4.9

\* Combined water 16.3 percent; carbon dioxide 7.8 percent.

On the basis of the data in Table III, the hypothetical mineral composition of tubercles in pipe No. 125 was calculated, as follows:

Zinc hydroxide is white or yellowish and zinc carbonate is colorless; both are soluble, but only in minute quantities in water.

Percent

Zinc hydroxide, Zn(OH) <sub>2</sub> .....	60.9
Zinc carbonate, ZnCO <sub>3</sub> .....	22.3
Cuprous oxide, Cu <sub>2</sub> O.....	1.9
Iron hydroxide, Fe(OH) <sub>3</sub> .....	3.2
Silica, SiO <sub>2</sub> .....	5.3
Combined water, H <sub>2</sub> O.....	4.8

98.4

The yellow coloration of tubercles, and especially of the deposits on the inside surfaces of pipes, was often noticeable. A greenish tint also was frequently found, apparently caused by the presence of malachite. The amount of cuprous oxide in the tubercles was small. Iron and silica were deposited from the water.

been attributed to the action of air bubbles that adhere to the wall of the tube and prevent its cooling by water, thus causing a local superheating and subsequent pitting of the wall.<sup>10</sup> We could not find any evidence for or against this theory in the present investigation of corrosion in brass pipes. Of course, there are essential differences in the operating conditions of boiler tubes and hot-water pipes, especially in the considerably higher temperature range of the boiler tubes.

Our observations indicated that at least in some cases local corrosion had started under the influence of residual stresses and local deformations. The evidence gathered in support of this contention can be summed up as follows:

1. Incipient plugs were found within pipe walls at the end of cracks (Figure 8). The metal surrounding the plugs obviously had



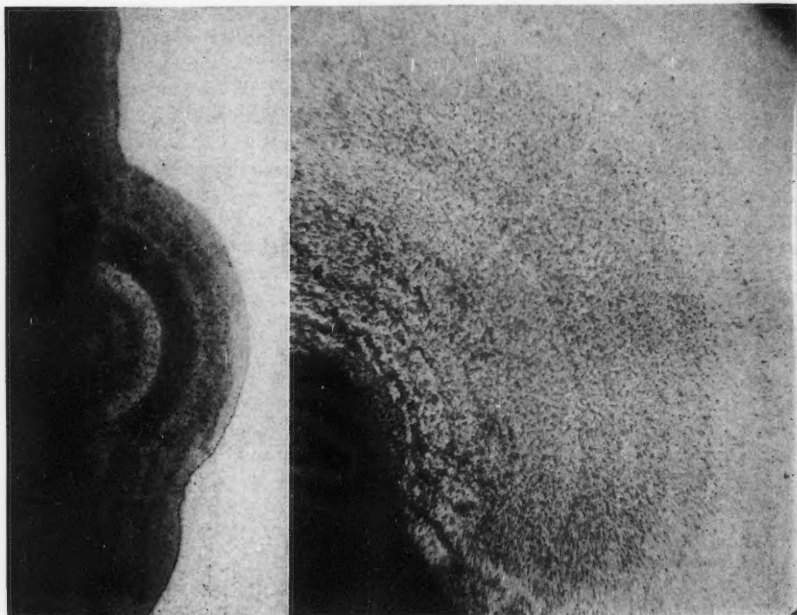


Figure 6

Figure 7

Figure 6—Plug developed by layer corrosion, pipe 134B.  $\times 15$ .

Figure 7—Zonal structure of plug, pipe 93.  $\times 25$ .

been strained before cracking.

2. The outlines of original cracks often can be traced in the center of plugs.

3. A crack was found at the root of a small plug in one of the pipes.

4. In another pipe a large number of incipient tubercles had developed within surface grooves where the metal had been deformed. These grooves originated in the pipe processing (Figure 9).

5. A plug was found piercing the wall at an angle. Instead of developing in a direction perpendicular to the wall, as usual, the prevailing growth of this plug extended along the pipe length. This showed the tendency of corrosion to follow the lines of straining produced by cold-

drawing. A crack also was discovered in the same section.

6. Plugs always had oval shapes in tangential sections of pipes, with the longer axis parallel to the pipe length (Figure 10). The accelerated corrosion of the metal in the specific direction again suggests the influence of straining.

The processing of brass pipes involves cold-working, all traces of which are not always removed by the subsequent annealing. Some grains of pipes often showed a distortion of shape or presence of slip bands—a distinct proof that the stresses had not been entirely eliminated. Microscopic cracks found in the walls of some pipes are also significant (Figure 11). As they fre-



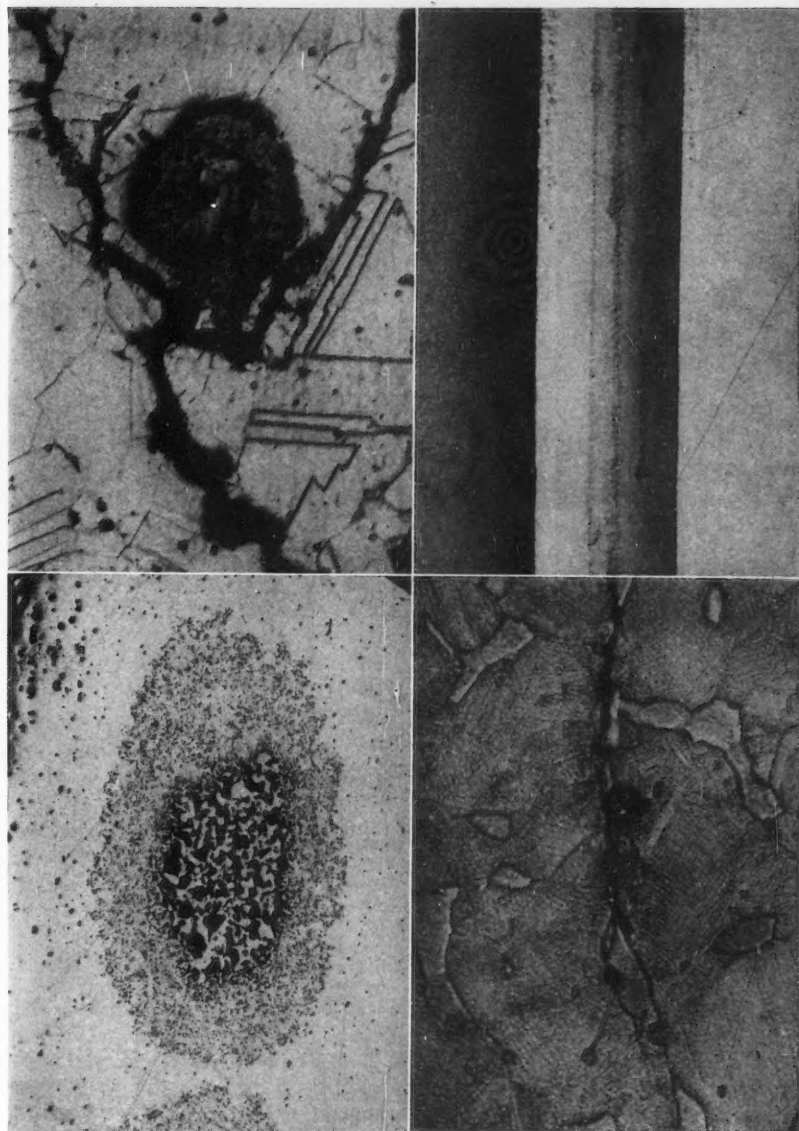


Figure 8—Upper left: Incipient plug at fork of cracks, pipe 53.  $\times 300$ .  
 Figure 9—Upper right: Parallel rows of tubercles, pipe 24. Natural Size.  
 Figure 10—Lower left: Oval section of plug, pipe 200D.  $\times 30$ .  
 Figure 11—Lower right: Slip bands and crack, pipe 149.  $\times 750$ .

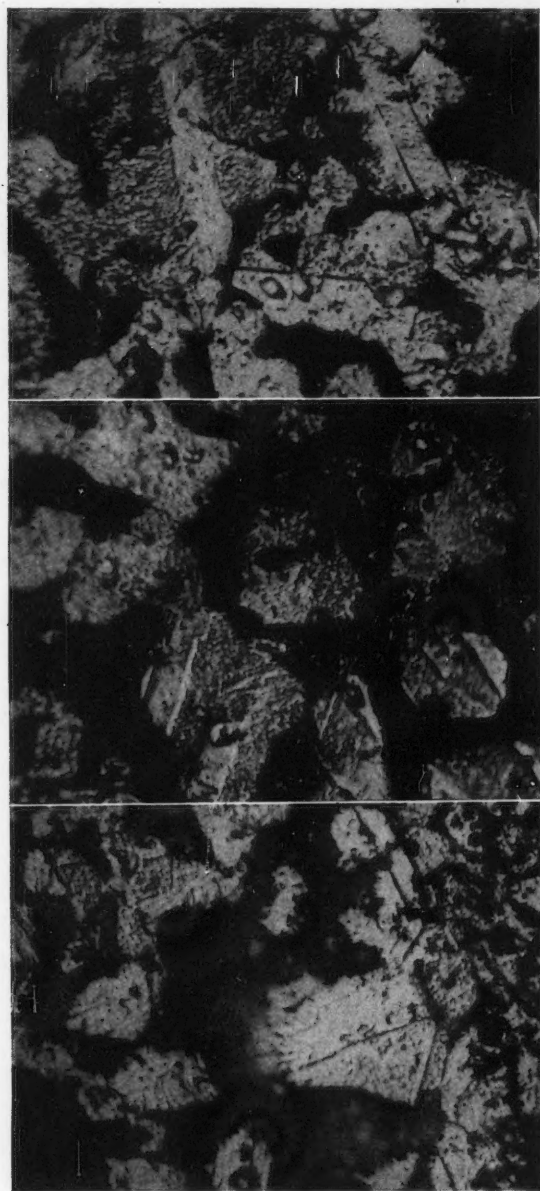


Figure 12—Twins of former alpha in copper plugs.

- a. Top—Pipe 200D,  $\times 1400$ .
- b. Center—Pipe 134B,  $\times 1400$ .
- c. Bottom—Pipe 31,  $\times 750$ .

quently occurred in the middle of a wall section, their origin should be attributed to local stresses.

It appears certain that two or more kinds of stresses can coexist in metals. The stresses of one kind can be removed by a low-temperature annealing, but not necessarily all the stresses associated with deformation and slip. The accelerating effect of residual stresses on corrosion of metals has been pointed out by all investigators of stress corrosion.

#### **Are Copper Deposits Residual or Redeposited?**

The concept of selective corrosion of the zinc of brass was developed as early as 1903, by Milton and Larke<sup>4</sup> and later was supported by experimental work of Desch and Whyte.<sup>1</sup> They came to the conclusion that copper was residual. This viewpoint was suggested by some investigators of corrosion but opposed by others who believed that the copper had been dissolved and redeposited.

The authors believed that the controversy could be resolved by a microscopic study of the structural characteristics of the copper deposits. It seemed certain that if the zinc had been selectively leached out, some of the structural aspects of the original metal should still be found; as, for instance, twinning of alpha grains. On the other hand, assuming that copper had been redeposited, the microstructure of the deposits should necessarily be typical of metals precipitated from aqueous solutions. These considerations prompted the authors to study more particularly the copper deposits, especially in plugs contain-

ing large amounts of copper, which therefore offer a greater field for observations.

#### **Dezincification of Alpha in High-brass Pipes**

The search for twinning in corroded grains of alpha brass was successful. In a small plug of pipe 200D made of high brass the grains of alpha had been entirely converted into copper, yet some of them showed distinct twinning (Figure 12a). The boundaries of some of these grains remained well visible. Although these grains were only a few among many others that had been merged into a solid mass of copper, apparently structureless, it was evident that the real structure of the deposits could not be observed because of the presence of minute holes. In order to obtain a proper depth of etching of the deposits in further work, "spot etching" was used as described in the preceding pages under Microstructure. Small drops of dilute solutions of ammonium persulphate in water (concentration 5 to 10. percent) were placed on copper deposits for various periods of time. By means of this technique twinning of former alpha grains, in the deposits of other pipes (134B, 31, 101) was brought out (Figures 12b and 12c).

#### **Dezincification of Alpha in Muntz-metal Pipes**

In the plugs of alpha-beta brass pipes, both constituents were completely replaced by copper but were not entirely merged. The "alpha" in plugs of pipes 5, 7H and 54, which were all made of alpha-beta brass, clearly showed twinning in some of the alpha grains now completely replaced by copper. In other Muntz-

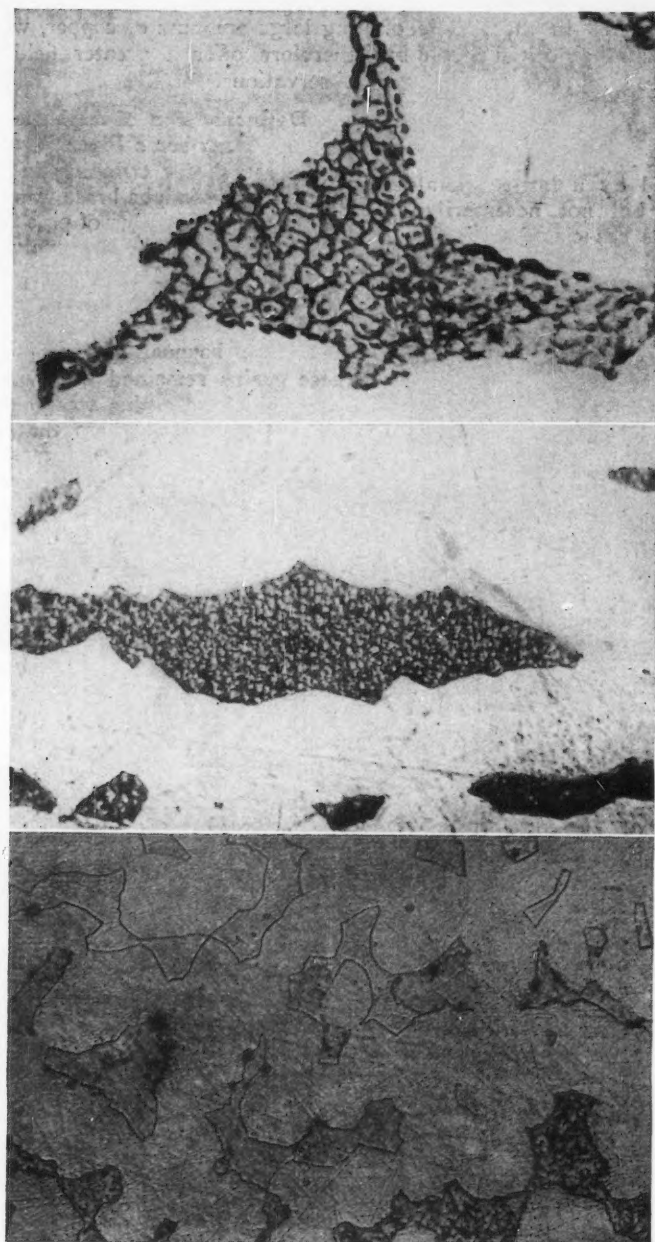


Figure 13—Dezincification of beta.

*a.* Gradual dezincification, pipe 73.  $\times 400$ .

*b.* Roughening of surface in initial stage, pipe 125.  $\times 1500$ .

*c.* Final stage, pipe 54.  $\times 2000$ .

metal pipes examination failed to reveal it because of the porous structure of the copper. The final conclusion based on all observations was that twinning remained in dezincified alpha grains of both alloys, high brass and Muntz metal. If we assume now that copper had been redeposited, the question arises as to how the atoms of the copper could have placed themselves into the exact positions of the original grains of brass, so as to reproduce the twinning. It is known that twinning of brass grains is caused by mechanical work followed by heating. It is improbable that the pattern of the grain structure originally caused by mechanical work and heating could have been restored by precipitation of a solid from a solution, and the authors believe that the presence of twinning in the skeletons of former alpha grains is a decisive proof that the zinc had been leached out and the copper left behind.

### Dezincification of Beta

In regard to the origin of copper derived from dezincification of beta, the question still remained open. In all deposits beta could be distinguished from alpha by its much darker color and by its shape. The origin of the copper could not be established by the presence of twinning, for beta does not form twins. Corrosion of beta is different from that of alpha in two respects: (1) beta is always attacked first, (2) dezincification of beta is often gradual, while that of alpha is always abrupt.

In many pipes the first sign of dezincification was change in the color of beta, which turned black.

In these pipes there were three kinds of "beta" patches near the plugs: (1) completely filled with copper, (2) black patches and (3) normal golden yellow (Pipe 16, Figure 13a).

Microscopic study of dezincification of beta at high magnifications revealed that in the initial stage only slight roughening of the beta surface occurred (Figure 13b). This change is responsible for the discoloration of beta, apparent at lower magnifications. The real structure remained unresolved. In the final stage of dezincification the view cleared up, and the copper was distinctly seen completely filling the space of the former patches of beta. It contained many black and reddish brown lines and dots (Figure 12c).

The latter were first interpreted as a structural constituent but after repeated examinations the reddish specks were found to be pits in the copper with bright walls, which reflected the natural color of this metal. It became evident that the porous copper was the only product of dezincification in its final stage, as far as the microscope could reveal. All further efforts to determine the structure of the copper have failed. Judging from the fact that completely corroded patches of "beta" were maintaining their shape for a long time, until an increased porosity and the ultimate oxidation of copper had destroyed all vestiges of the original structure, the authors are inclined to believe in the residual origin of the copper formed by dezincification of beta. The preservation of shape indicates that the process did not entirely ruin the



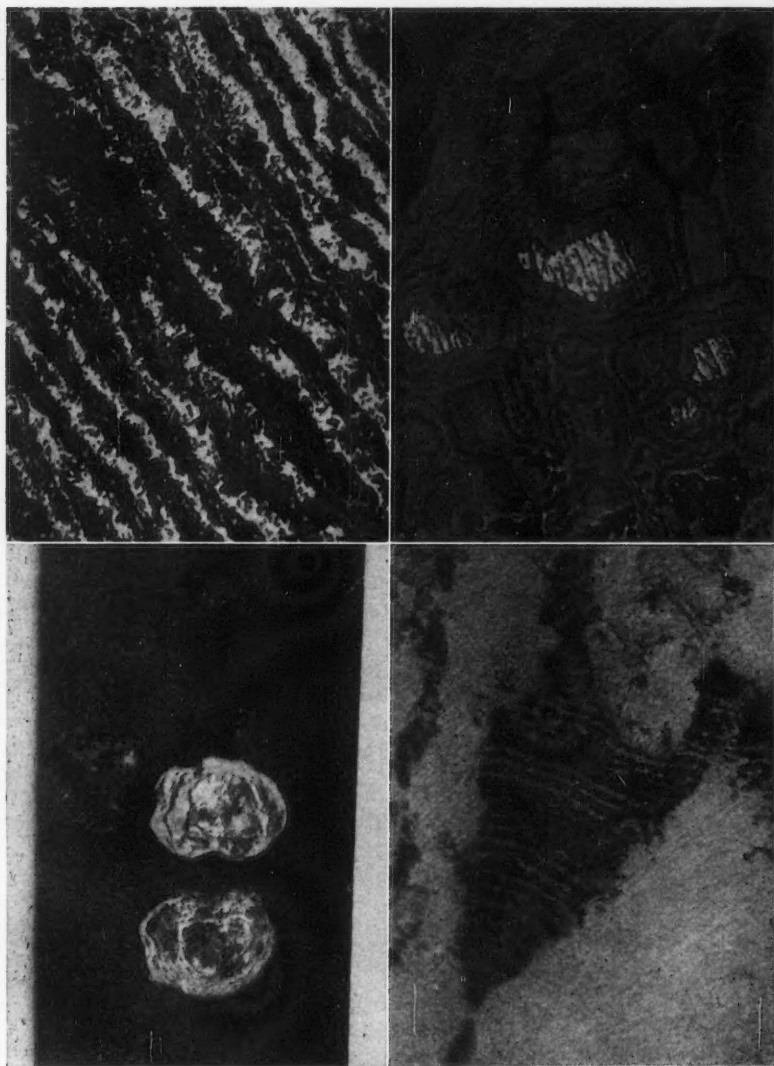


Figure 14—Periodicity of corrosion.

- a. Upper left—Parallel bands of cuprite and malachite in ancient bronze.  $\times 100$ .
- b. Upper right—Zonal structure of corroded grains in ancient bronze.  $\times 1000$ .
- c. Lower left—Fracture of tubercle, showing concentric shells.  $\times 3$ .
- d. Lower right—Alternating bands of  $\text{Cu}_2\text{O}$  and copper in corroded beta, pipe 125.  $\times 1000$ .



skeletons of beta that continued to exist.

It would be erroneous to say, however, that precipitation of copper does not occur in the corrosion of brass pipes. Evidence of such precipitation was found by the authors in one of the tubercles where small deposits of copper were disclosed among other minerals, but this copper had been carried by the corrosive water from somewhere else and not deposited in situ.

### Periodicity of Corrosion

Periodicity of corrosion processes has been mentioned in the literature by one of the authors<sup>20</sup> who observed in the patina of ancient bronzes parallel bands of cuprite and malachite arranged in alternating order (Figure 14a). These minerals are common products of corrosion of old bronzes. In some specimens the number of bands exceeded 50 and their average width was from 4 to 5 microns. The formation of these bands in bronze patina could be explained only by a certain periodicity of the corrosion process. At first it was attributed to seasonal changes in the burial ground, but when further examinations revealed similar periodicity within individual grains of bronze that were partially or totally corroded, the periodicity appeared closely associated with the mechanism of corrosion within the crystals (Figure 14b). These grains contained concentric zones of two different mineral products arranged alternately. It seemed as though the corrosion of each grain had been going on with a periodical rise and drop of concentration of the cor-

rosive liquid, or passing through a cycle of some intermittent chemical or electrochemical changes.

Periodic type of corrosion was found in ancient copper and silver also. During the present examination of brass pipes it was first encountered in plugs and tubercles. The structure of plugs consisted of many concentric zones distinctly visible in their vertical and horizontal sections (Figure 7). As has already been explained, the main difference between the zones was in the amount of porosity, the dark zones being more porous than the light ones. Periodicity of a tubercle's formative process was evident from the presence of many concentric shells in the walls of tubercles (Figure 14c). Often the shells were separated by spaces.

A different type of periodicity was revealed in pipe 125, where some patches of corroded beta showed numerous stripes (Figure 14d). At high magnifications they appeared to be bands of metallic copper alternating with bands of cuprous oxide. The total number of these bands in one patch of beta was 60 on a length of 75 microns, the average width of each being slightly over one micron. We can only speculate as to the reasons why the beta in this particular location was not converted into solid copper or solid cuprous oxide as it was in all other corroded parts of the same pipe.

In conclusion, it should be noted that inasmuch as corrosion causes structural changes, the current theories of corrosion should take these changes into consideration.

### Summary

The corrosion of yellow brass pipes removed from domestic hot-water installations was studied under the microscope in relation to their microstructure and conditions of service. Particular attention was given to the study of the structural aspects of corrosion, the origin of local corrosion, the nature of copper deposits, and general conditions of dezincification. The results are briefly outlined below:

1. All pipes were found corroded, but the rate of general corrosion per year was small, and some specimens were in good condition after 20 to 25 years of service. However, most of the pipes exhibited local corrosion, which was much more destructive.
2. The size of grains apparently had no effect on corrosion, except perhaps when it varied considerably; but the surface defects of pipes, the residual straining of metal and cracks were influential factors.
3. Corrosion of both constituents of brass, alpha and beta, had two distinct stages, dezincification and the final corrosion of copper formed. The lag between these stages varied considerably.
4. In alpha-beta brass pipes, the beta was always attacked first, but here also the lag varied considerably.
5. Microscopic examination revealed that local corrosion in some pipes was closely associated with residual stresses and local deformations. The evidence thus obtained pointed to the conclusion that these factors were influential in starting the localized corrosion in these pipes.
6. Conclusive evidence of the residual origin of copper derived from dezincification of alpha was found in the structural characteristics of the deposits. In regard to the copper derived from dezincification of beta, the residual origin is the most probable.
7. The presence of alternating zones in plugs and also the zonal structure of tubercles indicated that some periodic changes were involved in the process of corrosion. Further evidence of periodicity was found in corroded "beta," which displayed parallel bands of copper and cuprous oxide arranged in alternate order. Periodicity of corrosion observed in other metals is mentioned.

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# Control of Galvanic Corrosion of Iron

By C. K. Donoho and J. T. MacKenzie

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IN ARID soils or poorly conducting media the electro-chemical corrosion of iron and steel is usually initiated by some heterogeneity of the environment, such as oxygen concentration cells, variations in acidity, etc. In more homogeneous and conducting media the causation potential of the electro-chemical corrosion of iron and steel structures is more often due to differences in potential between elements of the structure itself. Both of these two distinct types of corrosion attack are encountered in soil corrosion of ferrous metals, the controlling type depending upon such factors as aeration, soil resistivity and moisture.<sup>1</sup>

Among structures subject to the electrochemical corrosion by potential differences in the material itself, are pipe lines in salt and/or marshy soils, condenser coils immersed in aqueous coolants, and others where the environment is conducting and relatively homogeneous.

In the "graphitic" corrosion of cast iron the causation potential is the very significant potential between graphite as cathode and ferrite as anode. This type of micro-cell galvanic corrosion is, however, not the most destructive as the effect is a uniform attack over the entire surface and not concentrated on any particular area. In fact, the existence of the graphite-ferrite

cells may be even beneficial in partially masking grosser intra-structural galvanic corrosion.

When, for some reason, there exists a distinct potential difference between two parts of a metallic structure in a conducting medium the more cathodic part is protected from corrosion, but at the expense of the more anodic element, which may be rapidly corroded to uselessness.

Under such conditions it is important that if galvanic corrosion must occur the more anodic element should not be a vital part of the structure. The intensity of the galvanic attack increases as the cathode area increases, therefore it is also important that the more anodic element should not be a relatively small part of the structure. This area effect is aptly illustrated by the case of copper pipe joined by an iron coupling. In a conducting solution the coupling will be rapidly corroded because it is the anode, where all the attack is concentrated. Also such reactions are usually cathode controlled, and a large cathode area admits easier depolarization of the cathode by dissolved oxygen. In the opposite case, where a copper coupling is used on iron pipe, the corrosion is not so serious because the attack is spread out over the larger area of the iron anode and the access of oxygen to the cathode is

relatively slight, therefore depolarization is extremely slow.

Iron and steel structures for use in environments conducive to galvanic corrosion are rarely so similar chemically and physically in every part that the entire structure is electro-potentially equal. Where the potentials of various parts of connected structures are left to chance, serious failures may occur if a small element is for some reason slightly but definitely anodic to the rest of the structure.

Iron can be made relatively more cathodic by alloying with more noble elements which form simple solid solutions with the iron. Two such elements commonly used are nickel and copper. Lamdau and Oldach<sup>2</sup> showed that nickel alloyed with iron progressively changed the potential in 4 percent NaCl. In their tests it was shown that 40 percent nickel changed the potential of pure iron 0.4 volts. Copper is usually cathodic to nickel and would be expected to have a greater effect in iron. However, copper is not as soluble in iron as is nickel. At equilibrium, only about 0.4 percent copper is soluble at normal temperature, but unless the metal is cooled very slowly as much as 2 percent copper in iron will make an apparently homogeneous alloy. Alloying of steel or iron with a small percentage of nickel or copper makes a metal which under usual conditions is cathodic to otherwise similar unalloyed steel or iron.

#### Tests

In making fusion welds of cast iron pipe the operator usually tries to make the weld of the same composition as the basic metal. It has been found, however, that in many

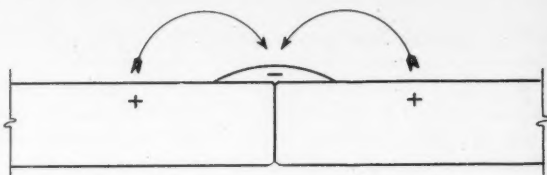
cases the weld, because of either chemical or physical dissimilarity, becomes anodic when the pipe is immersed in a conducting solution. In some services this will result in the corrosion being concentrated on the small area of the weld metal, causing rapid failure. Bronze welded pipe on the other hand is usually satisfactory because the weld metal is cathodic.

The polarity of welds may be determined most easily by what is known as the agar test. A machined section of the pipe wall through the weld is placed in a clear agar jelly which contains dissolved sodium chloride, potassium ferricyanide, and phenolphthalein. The same solution serves as the electrolyte, and galvanic action starts immediately. Anode points are revealed by the fact that iron going into solution reacts with the potassium ferricyanide to produce a deep blue color in the jelly adjacent to any anode point. Cathode points are shown by a red color in the jelly which is caused by the sodium hydroxide forming at the negative poles and changing the color of the phenolphthalein.

Figure 1 shows a section of a bronze weld of mono-cast pipe in which the polarity was determined by this method. As may be seen, the weld metal is cathodic to the pipe itself so that the corrosion would not take place on the weld, but would be spread out over the entire pipe. For this reason, bronze welded cast iron pipe presents no serious corrosion problem.

Figure 2 shows a section of a cast iron fusion weld. In this case the weld metal is distinctly anodic to the rest of the pipe and under favor-

Figure 1—Bronze weld.



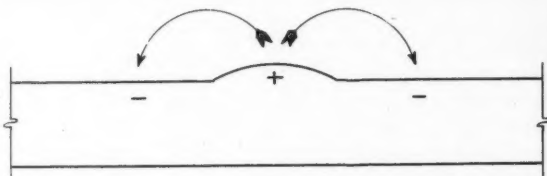
able conditions the galvanic corrosion might easily cause failure through concentration of the attack upon the weld.

Figure 3 shows one way in which this problem is solved. In this case the fusion weld was made with a 1 percent copper alloy cast iron for the weld metal. In this case the weld has become cathodic to the pipe wall and therefore no corro-

bolt and nut were of the same composition, in the other two the nuts were alloyed with copper. After one year exposure the weight loss results shown in the table were obtained.

From this test it is seen that the direction of the galvanic corrosion between bolt and nut may be controlled at will by alloying with copper.

Figure 2—Plain cast iron fusion weld.



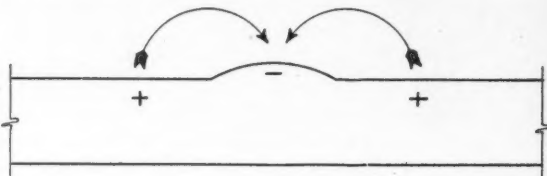
sion problems would be expected.

The practicality of this solution was checked by specimen tests in hot, aerated sea water. Where the weld metal was the 1 percent copper alloy the basic metal would be corroded severely while the weld metal was barely attacked.

Another test in hot sea water made use of four specimens consisting of  $\frac{3}{4}$ -inch cast iron bolts with screwed on nuts. In two cases the

A series of tests was initiated to determine the potential developed by coupling plain cast iron with cast iron containing varying percentages of nickel and copper. Induction furnace heats were made and several bars poured with successive small additions of the alloy to the crucible. By this method a series of bars was obtained with all elements constant except the purposely added alloys, copper or

Figure 3—Fusion weld. Alloy cast iron in weld.





BOLT	NUT	BOLT Loss in Weight		NUT Loss in Weight	
		Grams	Percent	Grams	Percent
Plain.....	Plain.....	36.6	12.6	21.1	19.5
Plain.....	Plain.....	31.7	10.2	19.3	20.5
Plain.....	0.5% Cu.....	53.5	17.1	5.0	4.0
Plain.....	1.5% Cu.....	57.5	18.5	1.9	1.6

nickel. Cells were set up using aerated 3 percent sodium chloride solution as the electrolyte and specimens 1.2 inch in diameter by  $\frac{1}{2}$ -inch long. The 1.2-inch specimens were polished on one face, the other surface being protected by paint and paraffin, and a connection made with protected copper wire. One plain cast iron specimen was used in each cell and coupled with an alloy specimen. Attempt was made to measure steady state potential differences between the two specimens in each cell. So many complicating factors enter into the measurement of small corrosion potentials, that the actual potential figures obtained in any one set of tests are not deemed reliable enough for presentation here. However, from these tests the following indications were obtained: (1), there is a sharp increase in potential dif-

ferences between plain cast iron and nickel cast iron up to about 2 percent nickel; (2), there is a somewhat slower increase in potential difference between plain cast iron and copper cast iron up to about 2.5 percent copper; (3), from 3 to 5 percent nickel the potential differences decreased, probably because of the formation of hard martensite; (4), above 2.5 percent copper the results were very erratic, probably because the alloys were not homogeneous; (5), above 12 percent nickel the potential differences become very high as the alloy becomes austenitic.

Fusion-welded cast iron pipe is often used in refinery condenser coils where the coolant is often brackish water or sea water. Trouble was formerly encountered in the rapid corrosion of the welds where

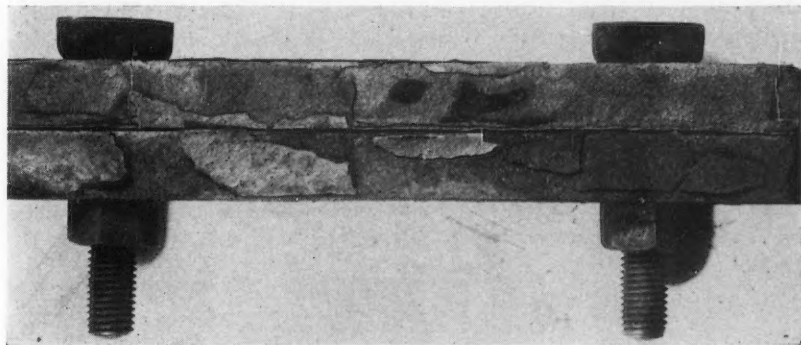


Figure 4—Plain cast iron bars bolted with alloy cast iron bolts and nuts after exposure in acidified salt solution.

the weld metal chanced to be anodic. By making the weld metal of 1 percent copper alloy, this trouble has been largely eliminated.

In similar condenser coils the mechanical joints of the pipe are made with bolts which are a pearlitic, malleable iron. A few years' experience showed that the bolts and nuts were failing while the pipe was still serviceable. The bolt and nut material was changed to a 1 percent copper alloy metal to make them cathodic to the pipe. See Figure 4. Since the change complaints of bolt corrosion have materially decreased. These low alloy bolts have been found valuable not only in condenser coils but also in other bolted

joint cast iron pipe lines which are frequently used for river and harbor crossings and for laying through marshes and swamps.

An interesting, though costly, mistake occurred in one of these condenser coils when a customer asked for 1 percent copper alloy pipe. By mistake these were furnished with the regular 1 percent copper bolts. Evidently, the alloy in the pipe was sufficient to make the pipe again cathodic, for the bolts failed in a short time. More highly alloyed bolts were furnished for replacement.

The authors feel that there are many instances where the control of galvanic corrosion of iron as outlined will prove valuable.

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The cover panel illustration shows typical ferrous pipe corrosion caused by many municipal supplies throughout the country. Such rusting and pitting usually occurs in waters whose chemical composition does not permit of the deposit of protective mineral films or scale, thus allowing the dissolved oxygen and carbon dioxide in the water to attack the metal. The vertical section has been mechanically cleaned of corrosion products and shows the extent of the pitting action. Note that the pipe has been completely perforated in some places. Leaks often are prevented by the accumulation of rust deposits over such perforations. Photograph furnished by Water Service Laboratories from specimen in their Corrosion Research Exhibit.

# Control of Pipe-Line Corrosion—A Manual

## Part II—Concluded from December, 1945

By **O. C. Mudd**

Chief Corrosion Engineer, Shell Pipe Line Corporation

### CORROSION CONTROL

#### Electrical Protection

The most practical method of retarding corrosion on pipe lines is the application of electric counter-currents flowing to the pipe so that the latter is continuously maintained in a "cathodic" state. (See Figure 22.) From this feature of the technique originates the term "Cathodic Protection." Sufficient current must

flow from soil to pipe to maintain a constant voltage difference at the soil-metal interface of 0.25 volts (approximately 0.80 volt between pipe and copper sulphate electrode in contact with soil) or more. This minimum voltage requirement has been determined by experience, and it may be subject to variations; however, pipe lines maintained under pipe-to-soil potentials of 0.80 volts

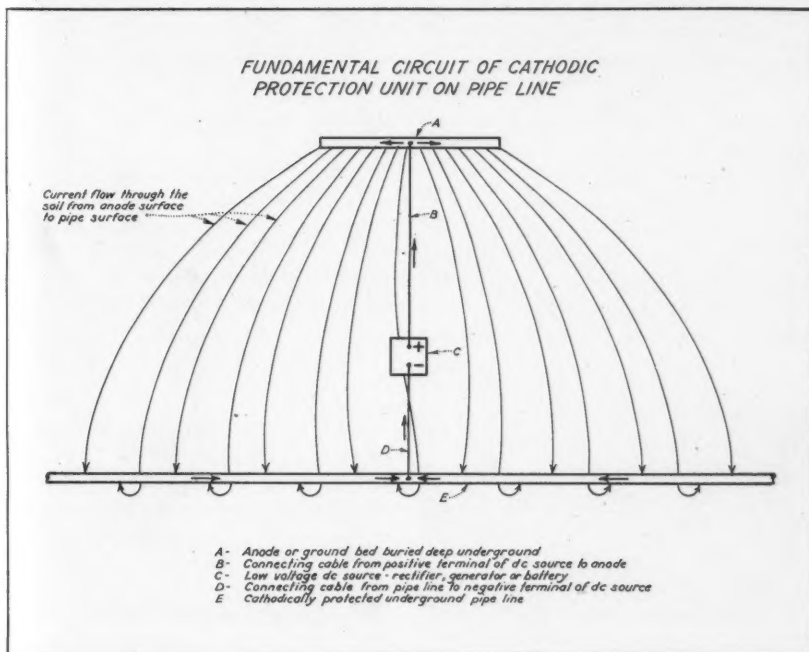


Figure 22—Fundamental circuit of cathodic protection unit of pipe line.

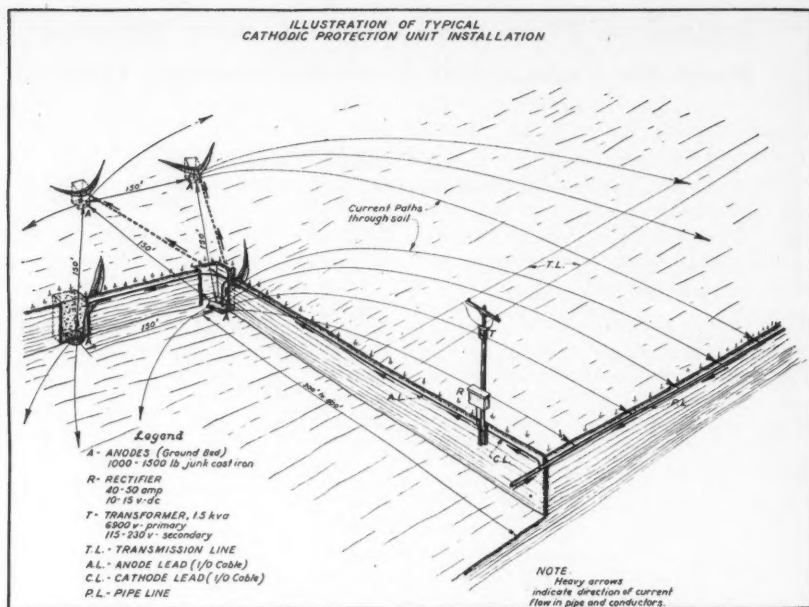


Figure 23—Typical cathodic unit installation.

or greater (measured with a copper-sulphate electrode) usually have stopped developing leaks.

To establish these desired protective conditions it is necessary, in corrosive areas, to create artificial electrolytic cells that will overpower or negate the opposite action of the soil chemical cells which have caused the damage by making portions of the pipe naturally anodic. Where the offenders are natural "concentration" cells, it is customary (1) to bury metallic masses to serve as anodes at a distance to the side of the pipe, and (2) to connect the positive lead from an external supply of direct current to each such anode or "ground-bed" and the negative lead to the pipe so that the current will flow from ground-bed to pipe

through the soil as illustrated in Figure 23.

Some important factors in power requirements to maintain the minimum soil-to-pipe potential of 0.25 volts depend upon the current density from anode or ground-bed metal surfaces exposed to the soil as well as the amount of moisture and the amounts and types of chemicals in the soil adjacent to these surfaces.

How to get effective service from ground-beds and connected direct current supplies at the most economical total of first cost and long-term operating cost is a prime problem of the corrosion engineer. A knowledge of available power supply units and the characteristics of ground-beds is prerequisite to planning effective and economical protection.

### Direct Current Power Supplies (Cathodic Protection Units)

A direct-current supply, e.g., rectifier or generator, with sufficient voltage and capable of delivering the necessary current is required for connection in the circuit between the ground-bed (anode) and the pipe line (cathode). A means of adjusting the output voltage also is required. Suitable units for the purpose are:

1. Rectifiers
2. Motor-Generator sets
3. Engine-driven generators
4. Wind-driven generators
5. Thermo-couple units

Rectifiers provide a most dependable supply because they have no moving parts or contacts. Available rectifiers are the contact type, the

thermo-ionic type, and the metallic-vapor type.

The contact-type rectifiers, which include copper-oxide, selenium and copper-sulphide units, are used extensively. These are rugged in construction and adaptable for operation at low voltages. They are susceptible to damage by moisture, and they decline in efficiency with relation to current output and age. Their initial efficiency is about 50 percent.

Thermo-ionic type rectifiers include the heated filament and the Ignatron units. The filaments have a limited life of about 1,000 hours, so replacements are frequent where a number of units operate continuously. The Ignatron is a new de-

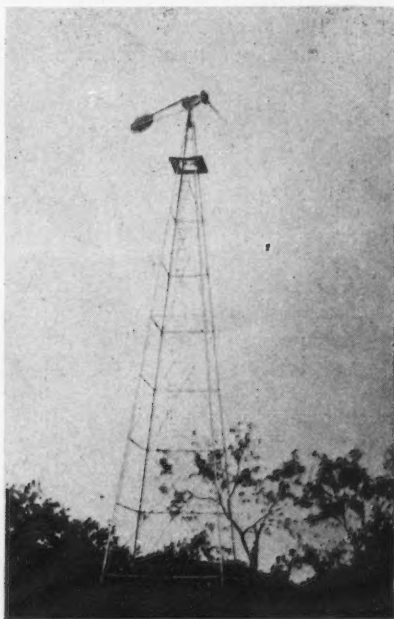
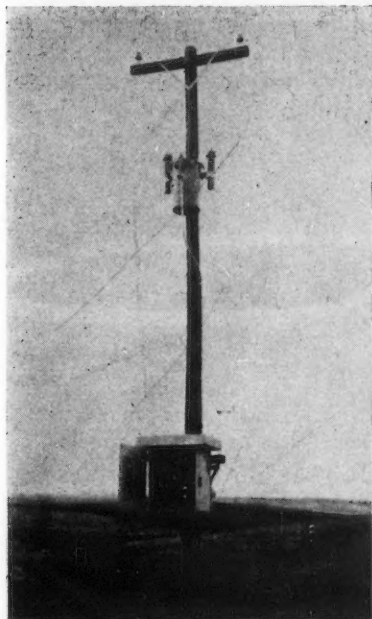


Figure 24 (Left)—Typical rectifier installation. (Right) Typical wind generator installation.

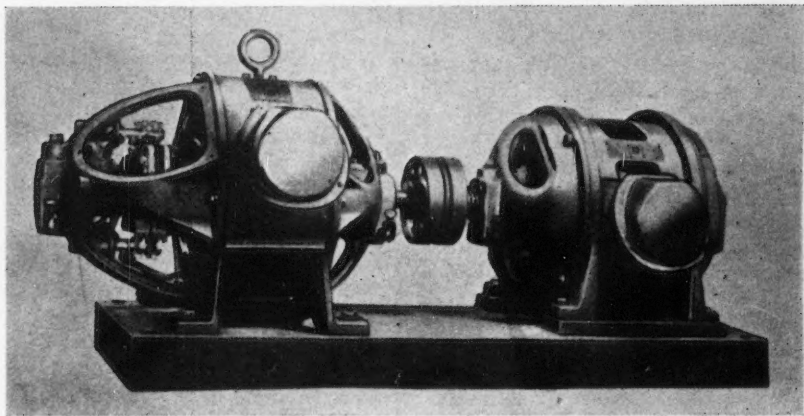


Figure 25—Motor-generator unit without mounting accessories.

velopment and has not yet been adapted to low voltage operation, but its efficiency is high for voltages above 100.

Metallic-vapor type rectifiers are applicable only where 30 volts or more are required. Their efficiency at 30 volts is about 50 percent, and it increases with increase of operating voltage.

Motor-generator sets of the size required for cathodic protection also have low efficiencies about equal to those of contact-type rectifiers. Their advantage is that increased operating voltages can be obtained without increase in capital cost. Their disadvantages are that they have moving mechanical parts which require maintenance and replacement. Low-speed units are preferable to those of high speed.

Both rectifiers and motor-generator sets must operate from a source of alternating current supply. This limits their application to places where such power is available.

Engine-driven generators are powered usually by automotive-type in-

ternal-combustion engines. Such engines are seldom able to operate more than 80 percent of the time, and in some the net operation time is 50 percent or lower. Maintenance and replacement of parts cause their operating costs substantially to exceed those of rectifier and motor-driven units operating on average purchased A. C. power.

Wind-driven generators of modern design are dependable in mechanical and electrical performance, but their output depends on wind velocity, which is extremely variable, and suffers periods of no output during calm weather. Excessive output from these units during unseasonable high winds may activate rather than retard corrosion by loosening corrosion products from the pipe line, thereby allowing an increase in corrosion rate when the unit is stopped.

Thermo-couple units have been constructed only on an experimental basis. A current output of 40 amperes has been obtained, but the metals tried have been able to de-



velop a potential of only 5.0 volts, which is too low in many cases for practical application.

Direct-current supply units are frequently installed out-of-doors where they are exposed to weather and other causes of trouble. Units so located require housings which will provide adequate ventilation and at the same time exclude rain, insects, birds and rodents. Figure 24 shows a typical out-of-doors contact-type rectifier mounting and a wind-generator installation. Figure 25 shows a typical motor-generator unit without accessory equipment.

### Anode or Ground-Bed Installations

The relation between an anode and current flow to soil is based on the electrical resistance encountered in radial flow from the anodic center of a soil body which is a portion or complete unit of a sphere or cylinder, so it is evident that the greater current density and voltage drop occurs at and near the anode surface.

The total amount of current that a given external voltage will cause to pass into soil of a given resistivity from an artificial anode or ground-bed—or from a group of such anodes (called "multiple anodes")—depends on the size and shape as well as the disposition and depth of insertion or burial of the anodes. Certain fundamental facts are known as to the final effectiveness and economy of cathodic protection installations.

**Driven or Vertical Rod Anodes:** Where driven rods (or tubes) are used as anodes, their ability to transmit current to the soil depends upon the depth to which they are driven and upon their diameter. As the depth of a rod of fixed diameter

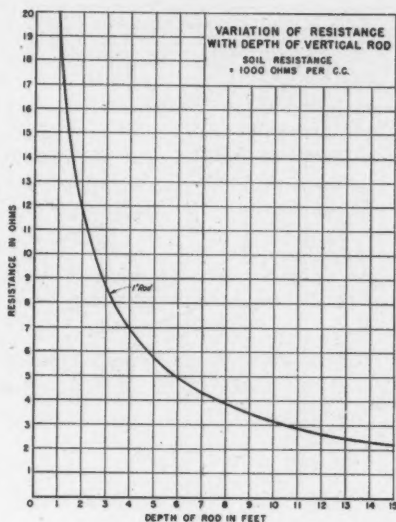


Figure 26

is increased, the total current transmitted also increases, but there is a logarithmic decrease in the density of current transmitted by each unit of rod area in contact with the soil. This is illustrated in Figure 26. As the diameter of rods driven to uniform depth is increased, the total current also increases, but the unit current density decreases rapidly. See Figure 27.

**Buried Horizontal Tube Anodes:** When horizontally buried rods or tubes, e.g., pieces of pipe, are used as anodes, their ability to transmit current to the soil depends upon their length and upon their diameter. As length is increased, the total current also increases, but the unit current density decreases logarithmically. See Figure 28. As the diameter is increased, the total current also increases, but the unit current density decreases rapidly. Also see Figure 28. Regard-

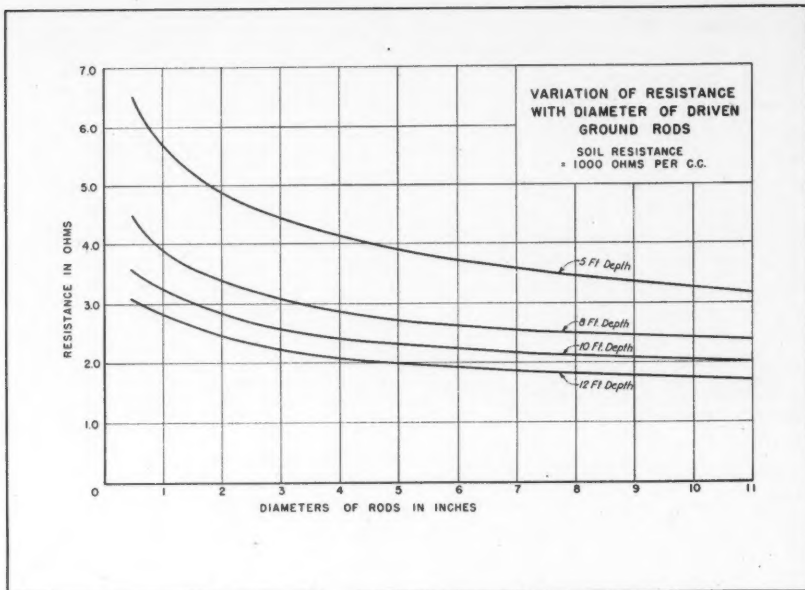


Figure 27—Variation of resistance with diameter of driven ground rods.

less of these factors, the optimum depth of burial usually is that of the soil of lowest resistivity to which it is practicable to excavate.

Multiple Anodes: From the foregoing it will be observed (a) that there is a practical limit to the

amount of current that can be introduced to the soil through a single driven or buried anode, and (b) that the use of a group of anodes is necessary when a substantial flow of current must be introduced at one location into the soil.

When multiple anodes are used, adjacent ones reciprocally reduce the current transmission ability of the others. For example, where two anodes are too closely spaced, they tend to act as a single one. Thus, for a given total current to be introduced at a given location on a corroding pipe line, there can be determined a minimum economic spacing of anodes. This requires a detailed knowledge of their reciprocal effects.

The principal fact in effecting spacing of adjacent anodes is anode diameter, because rod anodes of

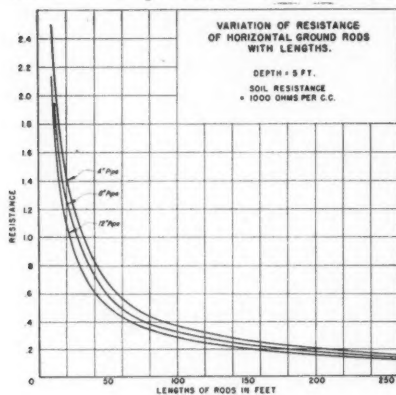


Figure 28

large diameter allow greater spacing for equal total current transmission. As spacing is increased, the total current transmitted is increased, but the rod surface unit current density decreases. As additional equal-diameter, equally-spaced rod anodes are added, the rod surface unit current density also decreases. Where several rod anodes are to be installed, the optimum spacing is approximately 50 anode diameters. See Figure 29.

For a cathodic protection installation in soil of a given resistivity, there can be determined an approximate economic balance between the cost of increasing the number of anodes and the resultant saving in cost of supplying required power over the expected life of the installation.

**Anode Materials:** Any current-conducting material is suitable for anodes or ground-beds; however, it is economical to use materials which will cost the least for the results obtained. Obviously these artificial anodes will be reduced or consumed in lieu of the pipe metal they are

installed to protect. With chemically pure ferrous iron, the loss is 20.1 pounds of metal per ampere of current transmitted per year. This pure metal, however, is too expensive for ground-bed use. The materials most frequently used, with their approximate unit losses, are listed as follows:

Material	Loss Pounds Per Ampere Per Year
Mild steel (junk pipe)	15-20
Cast iron (junk)	2-20
Carbon or graphite	2-0

Mild steel, such as junk pipe, is reduced at a near uniform rate in proportion to current, regardless of current density at the surface. If junk pipe (a relatively thin-walled material) is installed in long sections either horizontally or vertically, it may intersect strata of soil with various resistivities; and the portions exposed to the lower resistivity strata will be consumed first and thereby leave disconnected, unconsumed sections of pipe.

Junk cast iron usually has the advantage of being thick in section and of such form that any one piece will be in soil of uniform resistivity.

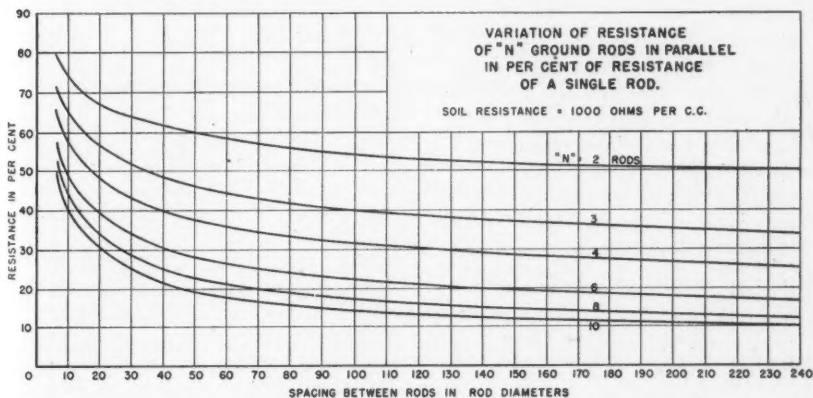
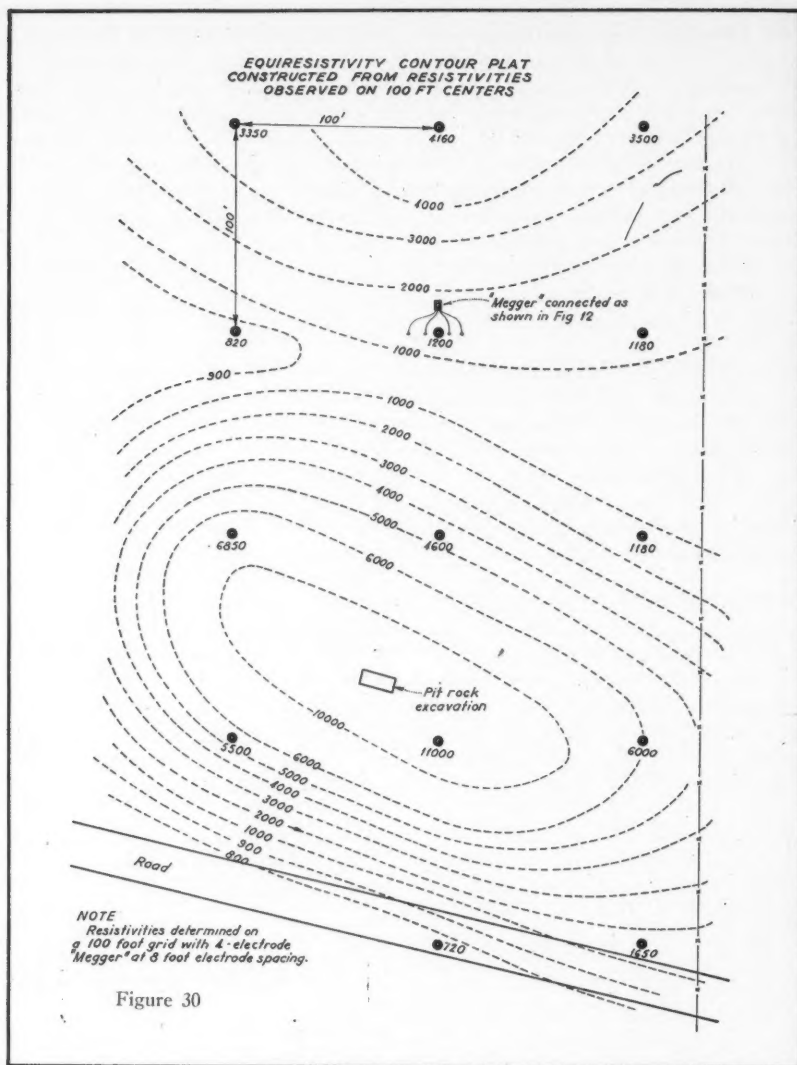


Figure 29



Also, the removal of outer iron leaves a graphite surface which—in contact with the deeper metal—acts as a graphite anode that reduces the rate of iron loss.

Carbon and graphite anodes have

been used to some extent, but variations in results obtained to date preclude definite statements as to their relative economy.

Anodes should contain sufficient material to assure a service life of

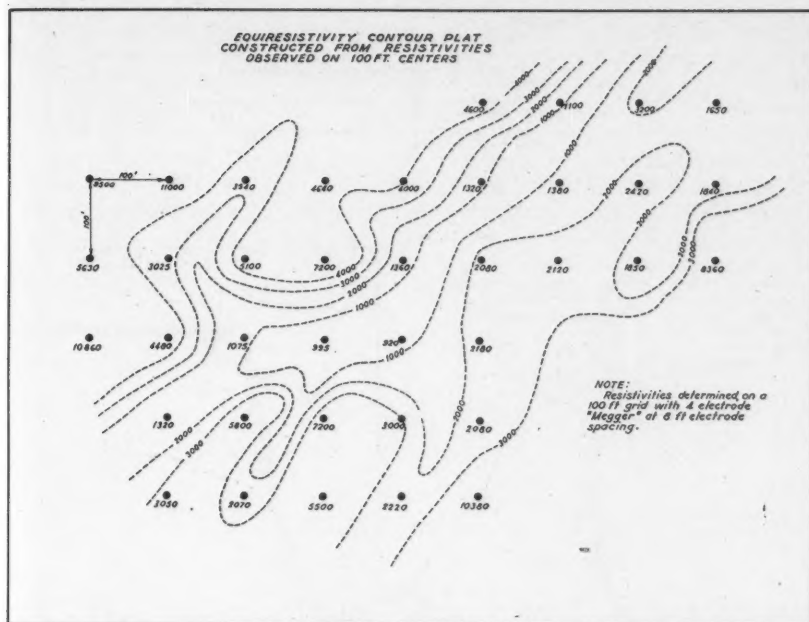


Figure 31—Equiresistivity contour plat constructed from resistivities observed on 100-foot centers.

15 to 20 years unless circumstances justify a shorter one. Their surface area should be large enough to give a surface current\* density of not more than 0.1 ampere or less per square foot. The initial loss from iron anodes of the above density will be near 100 percent corrosion efficiency, but this rate of loss tends to decrease over long periods and may be reduced to a corrosion efficiency of below 50 percent. Iron loss from cast iron anodes may drop to still lower corrosion efficiencies because of the residual graphite surface remaining after the iron has been removed by current flow.

Extreme care should be taken in design and installation of anodes because they are buried several feet, thereby making it costly to excavate

them for later inspection of their condition or that of their connections.

#### Soil Conditions at Ground Beds

Soil resistances substantially affect the power required with a given anode or ground-bed installation to establish the desired 0.25-volt soil-to-pipe potential drop essential to cathodic protection; therefore, the practice of placing anodes in soil of the lowest accessible resistivity near the prospective location is important. Such soil can be found in the vicinity of a proposed installation by surveying it over a grid pattern with the four-electrode "megger" equipment, using a test electrode spacing at each pattern point of 8 feet, which is approximately the depth to which the anodes usually

Figure 32

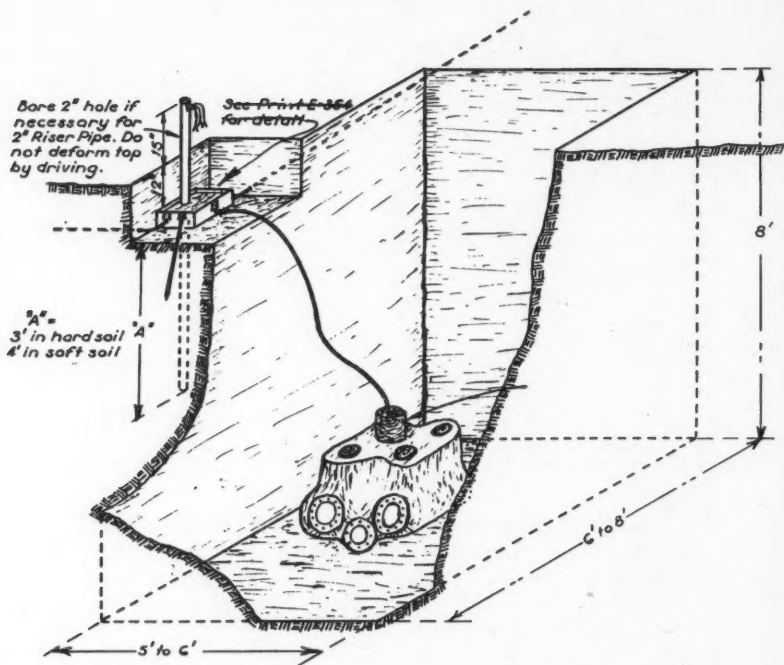
**NOTE:**

First three feet of backfill in anode hole to include chemicals to be added. Vent to be installed when backfilled.

See Print E-1766

Cover connection junction box with felt before backfilling.

Construct water-retaining dikes after backfilling.



are to be buried. (Surface indications of soil resistivity are of little value.) Figures 30 and 31 illustrate such surveys.

The local resistivity of soil surrounding anodes can be lowered by adding chemicals to the backfill. Where a 1000 to 1500-pound cast-iron anode is buried, the present practice is to add from 600 to 800 pounds of crushed gypsum (calcium sulphate, as mined) and 200 to 300 pounds of salt with the initial backfill. See Figure 32.

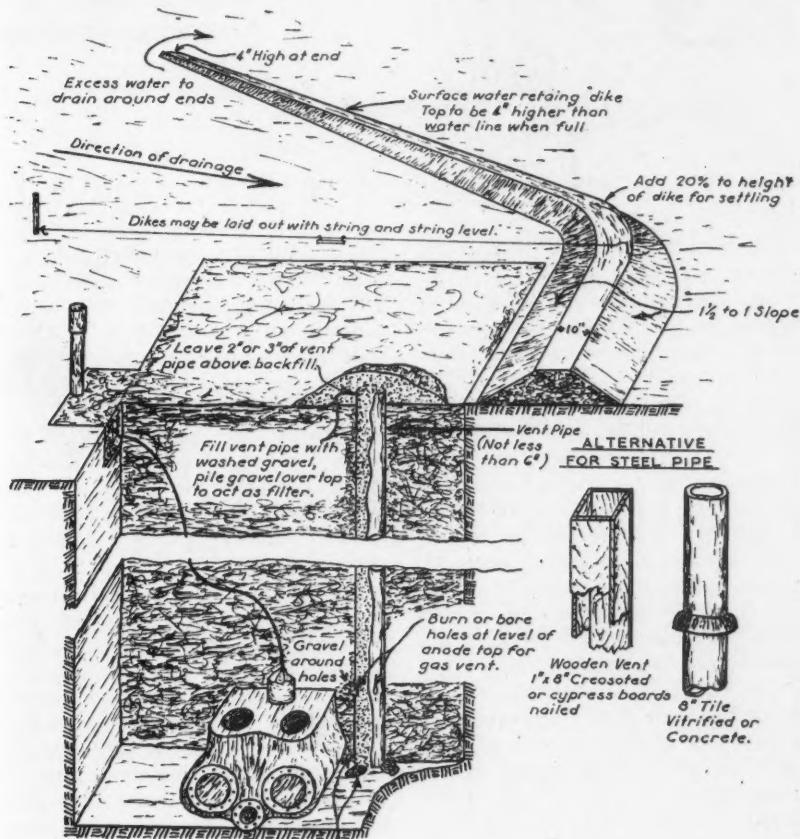
Water or a high concentration of moisture is essential in soil adjacent to anodes if the soil resistivity is to remain nearly constant. Soils usually retain a constant moisture at depths of 8 feet and more. Water is decomposed by current flow from the anode at the rate of 0.78 gallons per ampere per year, with accompanying liberation of oxygen; however, this loss is normally but a small fraction of that lost through atmospheric evaporation and heat generated by current flow. Every advan-



tage should be taken, especially in arid territory, to obtain or secure adequate moisture or water supply for anodes. See Figure 33.

The optimum distance between ground-beds and the pipe line depends upon the amount of current to be transmitted through the ground-bed and whether the line is bare, poorly-coated or well-coated.

With 40 to 50 amperes to be transmitted through a location to a bare or poorly-coated line, the distance should be 300 to 400 feet; however, with currents as low as 5 amperes the distance may be lessened to 15 or 20 feet. Ground-beds for a line well-coated with material of high electrical resistance may be placed nearer the line; however, the dis-



Set vent pipe near anode but do not allow steel pipe to make contact with anode. Place two or three rocks or pile of gravel under vent pipe to keep bottom open for water flow.

Figure 33

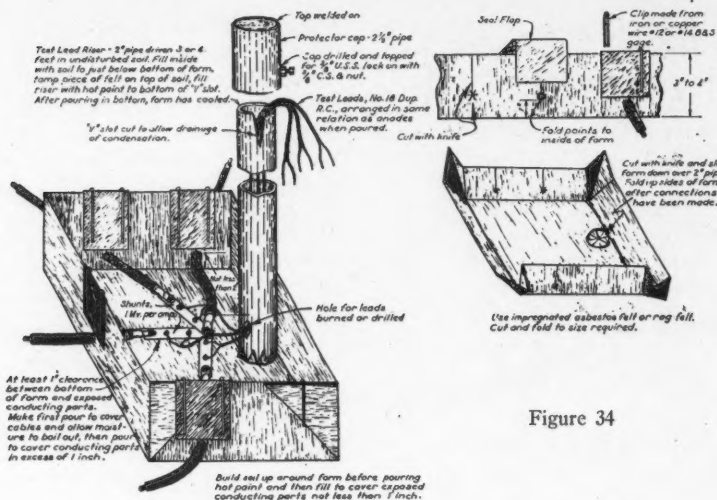


Figure 34

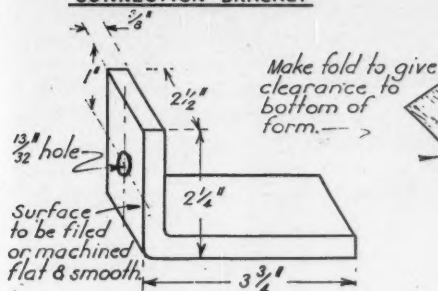
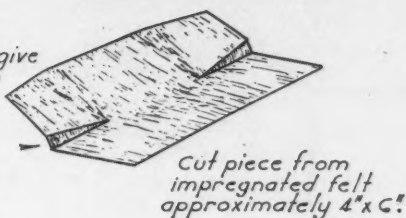
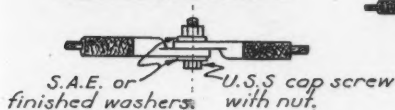
tance always should be sufficient to prevent imposing a soil-to-pipe potential directly opposite the grounded in excess of 2.5 volts (as measured with a copper-sulphate "half-cell" electrode).

### Underground Cables and Connections

Conductors used for connecting the elements of cathodic protection units must be large enough to prevent abnormal voltage drop. If placed overhead, the weight of copper in such conductors would require expensive construction, and they would be subject to easy theft. Placing conductor cables underground can be done by excavating trenches or plowing in with a "cable mole" at less expense than overhead construction, and it diminishes the chance of theft. Such underground cables, particularly near the connections to anodes, must be insulated to withstand exposure to moisture and soil over a period of years. Insu-

lation failure of an anode cable will result in rapid reduction of the conductor metal. Sheathed non-hygrosopic synthetic rubber underlaid with normal rubber insulated, 600-volt copper cable has been found to be most satisfactory.

Buried cable connections should have low resistances and remain tight. Present practice is to make them large enough for fastening with  $\frac{3}{8}$ -inch bolts. They should be protected against soil moisture during their entire expected service life. Present practice is to surround them with hot bitumen enamel with a thickness of at least one inch. Figures 34 and 35 illustrate typical methods of making and protecting connections. It is well to insert shunts in anode connections where they are installed; this allows later current measurements to be taken without opening the circuit. The latter is a process which requires excavating and tearing the insulation from each connection.

ANODE & PIPE  
CONNECTION BRACKETSTRAIGHT RUN  
INSULATING JOINT FORMSOLDER LUG  
CONNECTION DETAILNOTE:

All lug faces to be filed flat & smooth before connecting. Always use washer next to lug.



Tie string or wire around ends of form after wrapping around cable. Fill to 1" over cable with hot paint.

Fold top edges inward after cooling and before backfilling.

NOTE: All forms to be cleaned of dirt, moisture, or other foreign matter before pouring. Pouring to be done by steps. Dirt to be brought up around forms as pouring progresses.

BRACKET CONNECTION & FORM

Pour hot paint at least 1" above bracket.

Fold top in before backfilling.

Make form from strip of impregnated felt. Coil 3 or 4 layers thick.

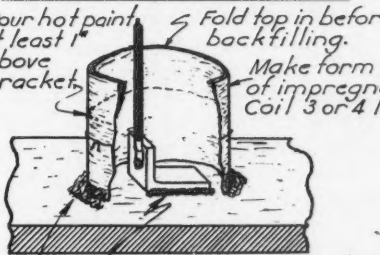


Figure 35

"Galvanic Anode" Protection

The foregoing sections discussed protective measures where cathodic conditions were established on pipe

line sections through use of an external direct-current power supply. A second method is the installation of "galvanic anodes" made of metals (e.g., zinc or magnesium) that are higher in the "electromotive series" than the pipe metal. When these are connected to the pipe through an insulated conductor, true galvanic cells are created that cause a flow of current through the soil from anode to pipe line without external power supply. These are effective until the

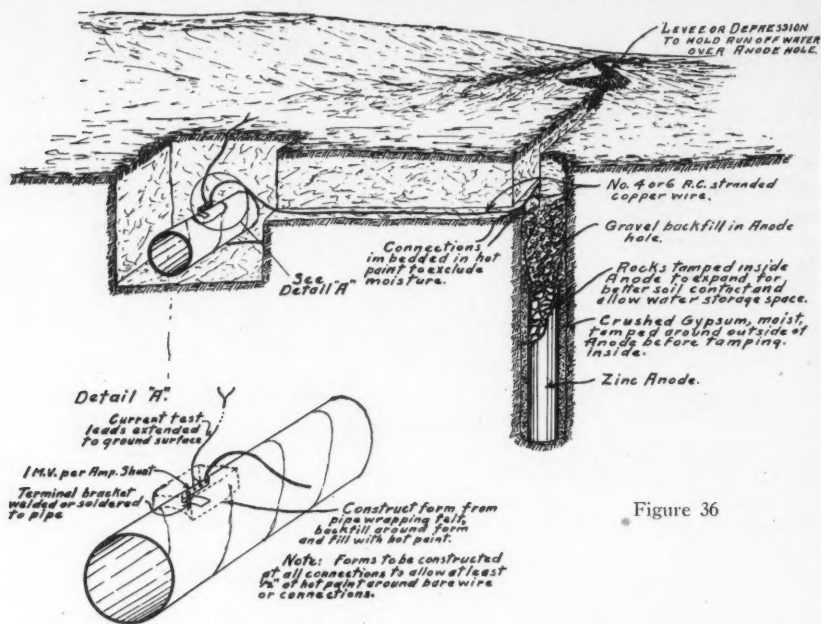


Figure 36

anode metal is consumed, after which it must be replaced. Pending this need or replacement (the time of which can be calculated from their current outputs), such installations require little or no attention and therefore have certain advantages over the use of rectifiers or generators.

Such installations combine the source of potential and the grounded in one unit. Since the potentials established by these cells are low, the current output also is low, thus making it desirable to locate the galvanic anode quite close to the pipe line or structure to be protected.

Zinc has been used as galvanic anodes for some time because local action of soil on the metal surface is slow and, therefore, the metal reduction by useful current flow ap-

proaches closely to that calculated; however, the potential of zinc with respect to iron is lower than desired. The addition of gypsum in the backfill around zinc anodes is necessary, and provisions should be made in arid sections to keep the beds moist by entrapment of surface water. (See Figure 36.) Operating records show that zinc galvanic anodes are satisfactory and economical under certain conditions.

Magnesium has been in use only a short time for galvanic anodes, and the technique of its proper installation is still being developed. Where installed in the same manner as is good practice for zinc, the useful current output of magnesium is far below that calculated, the loss being accounted for by local soil action. However, the relatively high potential between magnesium and

iron (1.96 volts) compared to that between zinc and iron (0.32) is an advantage that warrants further study of magnesium's effective utilization. The voltage between iron and magnesium of 1.96 volts is that taken from a standard publication table of Electromotive Force Series; however, the actual voltage between buried iron pipe and magnesium is found to be around 1.1 volts.

### Determining Distribution of Cathodic Unit Installations

Along a pipe line the proper locations for direct current cathodic protection units of a specified current capacity (usually 40 amperes at 10 volts on a 10-inch line) must be determined by tests with equivalent currents from two portable engine-driven generators made at trial ground-bed installations. These test generators should be able to develop a higher voltage than that of permanent units so as to allow the use of low-cost test ground-beds of higher resistance than permanent ones. Test units of practical size are 2.5-kw., 50-amp., 50-volt (name-plate rating) generators driven by four-cylinder gasoline engines and mounted on pneumatic-tired two-wheel trailers. Such generators may deliver 75 amperes with a corresponding decrease in voltage.

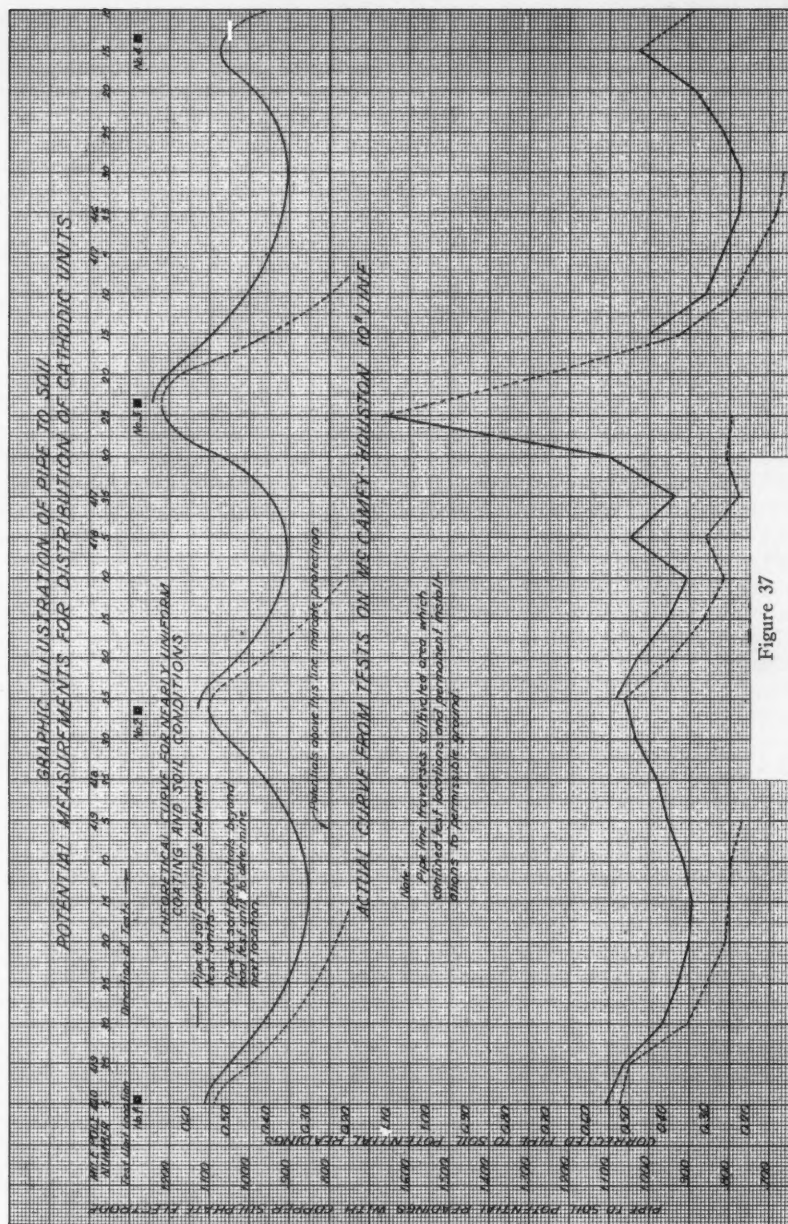
Temporary ground-beds are prepared 300 to 400 feet away from the pipe line by boring eight or ten two-inch auger holes four or five feet deep in the lowest resistivity soil that can be located. Single anodes of one-inch junk steel pipe of sufficient length to project above ground are inserted into these holes, after which salt and water are added around them. Copper cables from

the generator test unit are then connected, one from the negative terminal to the pipe line and one from the positive terminal to each of the inserted pipe anodes. After the generator is started, the number of the latter can be increased as required until the desired total current flow into the soil is obtained.

The first generator unit is connected to the pipe line and test ground-bed at one end of the line section along which cathodic protection is proposed. This unit then is operated at the desired current output for four or five hours to polarize the adjacent pipe surface. With the unit continuing in operation, pipe-to-soil potential measurements then are taken by the copper sulphate half-cell electrode method every 200 or 300 feet along the line, starting near the unit connection and progressing away from same. These progressive measurements of potential are continued until it is found to be less than 0.25 volts negative to soil (the minimum for effective protection). Such measurements are continued **beyond** the point of minimum requirement to make sure of having passed the limit of effective protection. (Note: If previous surveys showed that natural pipe-to-soil potentials along certain portions of the section under test were such as to cause local current flow from soil to pipe (i. e., cathodic), it will be necessary to check the new values and polarity of the artificially impressed test potentials only along those portions which had tested anodic.)

The second unit is connected to the pipe line and to a second temporary ground-bed at a distance from the first unit approximately







three times the length of line found under the effective protection (0.25 volts minimum) of the first unit. Both units are then operated simultaneously for the polarization period (four to five hours). With both units continuing in operation, the pipe-to-soil potential measurements then are taken from generator to generator to find if protection is complete. Insufficient protection between units requires moving the second unit and its ground-bed nearer to the first location, and repeating the test. Over-protection requires extension of the distance between them, and repeating the test. Over-protection not only is uneconomical but also may damage the pipe coating. As already stated, 2.5 volts is the maximum pipe-to-soil potential permissible—even near the units.

After an intervening section is found to be satisfactorily protected, the measurements are continued beyond the second unit to determine a third location to which the first unit and ground-bed should be transferred, and the above described procedure repeated until the entire section of pipe line to be protected has been covered and the number of permanent unit locations determined. Figure 37 shows graphically the theoretical and actual curves of pipe-to-soil potentials for satisfactory protection between successive test units and the determination of appropriate final unit locations.

The required spacing between these locations has been found to vary greatly. On a **bare or uncoated** ten-inch pipe line in the low-resistivity soil of one locality, effective protection would require 40-ampere cathodic units to be spaced an aver-

age of about every 750 feet. Such a close spacing of these expensive installations is economically impractical, and the indicated solution required that the bare pipe should be coated as well as cathodically protected. The other extreme of required spacing was found on a ten-inch pipe line in another locality where a single rectifier unit with only three amperes output provided complete protection along forty-five miles of mastic type coated pipe laid through swampy lands. One unit with five amperes output amply protected an equal length of this line primed and coated with coal-tar enamel and laid in soil having numerous low resistivity areas.

Pipe-to-soil potentials taken during tests along a **bare or poorly-coated** pipe line will be erratic—varying according to the variations of soil resistivity along the line. Such potentials along **well-coated** lines, due to the high resistance of the coating material, will be nearly uniform, with only a slight gradient away from the point of current supply. Any local depressions of potential along coated lines are indicative of coating failure.

The above discussion of spacing referred to "cathodic units"; however, to determine the proper distribution of "galvanic anodes," a different procedure must be followed. Whereas generator or rectifier units may afford protection to an entire length of bare or poorly coated line, "galvanic anodes" are effective to protect only isolated corrosive sections. Enough such anodes must be installed in the local area so that measurements made with two copper-sulphate half-cell electrodes (one placed directly above the pipe and

MATERIAL LIST PER PR. FLANGES			
ITEM	MATERIAL	NO. REQ'D	DIMENSIONS
"A"	Reinf. plastic or	= No. bolts	$\frac{1}{2}$ " wall thickness, Length = 2 x flg. thk., I.D. = ball size
"B"	other suitable matl.	= No. bolts	$\frac{1}{8}$ " thk., I.D. = ball size, O.D. = 3 x ball diam.
"C"	" " " "	= 1 per pr. flges	$\frac{1}{8}$ " thk., I.D. = I.D. of flg., O.D. = dimension "X"
"D"	Semi-steel	= 2 x No. bolts	Thickness = $\frac{1}{2}$ of ball diam., O.D. $\frac{1}{2}$ I.D. std.

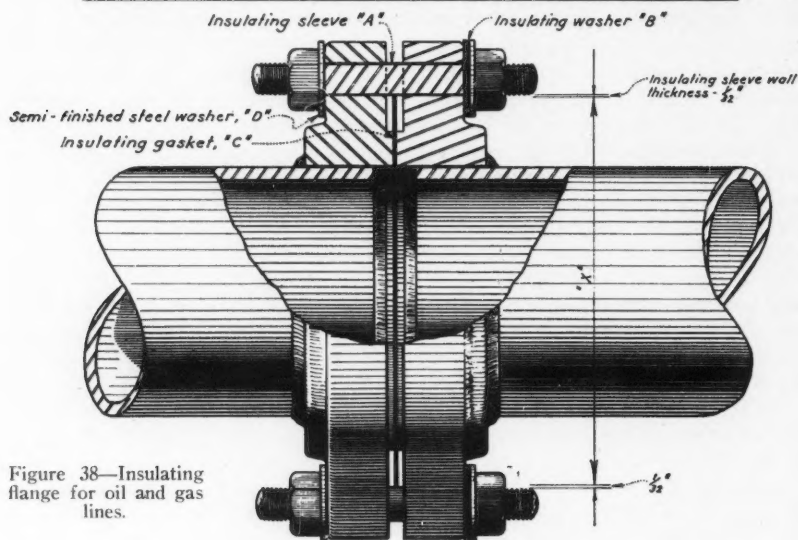


Figure 38—Insulating flange for oil and gas lines.

the other about five feet away at right angles to the line) will indicate a definite current flow from soil to pipe along the local section to be protected. The latter criterion must serve instead of the 0.25-volt minimum used for generator or rectifier protection, inasmuch as "galvanic anodes" will not normally establish voltages of that magnitude even though satisfactory protection is being given. Galvanic anodes giving a higher potential to iron may be practical and even economical to establish complete protection on bare or poorly coated lines. Complete protection can be attained on well coated lines with relatively few galvanic anodes.

### Insulating Connections for Pipe Lines

Pipe lines can be sectionalized electrically to control current flows of either galvanic or external origin. Usually this is done by inserting "insulating flanges," as illustrated in Figure 38, or equivalent insulated connections.

Pipe surfaces on each side of such insulating flanges should be protected from contact with soil for at least 50 pipe diameters in order to prevent concentrated flow of current from section to section around the insulation. This protection is obtained most effectively by placing the pipe above ground on suitable supports; however, where such a

plan is impracticable, an effective alternative is to apply extra-thick bitumen coating (free of imperfections) along the requisite length of pipe, and to completely encase the insulating flanges in the same coating material. A second but less certain alternative is to bury the requisite length of pipe in clean, well-drained sand.

The insulation of pump stations from main pipe lines is always desirable in order to prevent rapid deterioration of buried station piping or structures which may be anodic to the main line. It becomes necessary, however, where a cathodic protection unit is installed at a station to provide protection for the line to adjacent stations. Near the unit the pipe-to-soil potential on the main line must be relatively high to force the current to intermediate and extreme points for entry into the pipe and flow back to the station. These high potentials will cause prohibitive current flows to station mani-

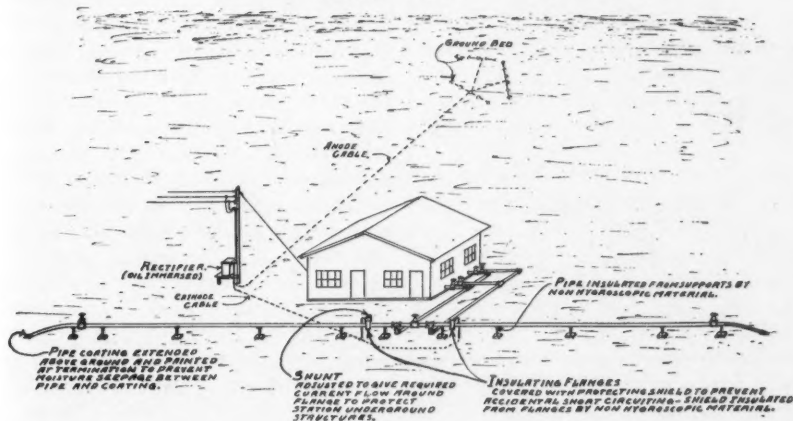
folds and structures unless the latter are properly insulated. Such structures may include buried service tanks, float and stock tank bottoms, buried conduits, deep well casings and numerous other uncoated pipes.

To insulate such a station, insulating flanges are placed in the main line on each side of the manifold piping. The negative terminal of the cathodic unit is connected to the remote side of each of these insulating flanges. Protection of buried station structures can be provided by installing across one insulating flange a shunt of sufficient resistance to conduct only the current flow required for station protection, i.e., enough to establish 0.25 volts structure-to-soil potential. Figure 39 illustrates such flange and shunt installations for a pump station.

Insulating flanges often can be installed advantageously along lines and at lateral connections to reduce corrosion by isolating the remaining pipe from extensive anodic sections

ILLUSTRATION OF TYPICAL INSULATING FLANGE  
INSTALLATION ABOVE GROUND AT PUMP STATION  
WHERE CATHODIC UNIT IS INSTALLED.  
(BAYOU SYSTEM)

Figure 39



such as tank bottoms, river crossings, gathering systems, and new pipe loops laid in the same right-of-way with old lines.

Insulating flanges should not be installed in existing lines until a complete analysis has been made of present current flow conditions and the probable effect of such installations.

### Bonding of Adjacent Lines and Structures

Buried pipe lines carrying current imposed by external sources may cause damage to adjacent buried lines. Even a line under cathodic protection is of such polarity as to induce current flows in crossing or adjacent foreign lines that will cause them damage if they are left unpro-

tected. Such damage may be prevented by installing a bond between the protected line and each foreign line. The current flow through such bonds increases the current flow through the soil to the foreign line which reduces the current flow from soil to the protected line; therefore, it is economical to limit the current through bonds only to that rate necessary to prevent damage. It is good practice to have representatives of each line involved present when bond adjustments are made.

The accepted technique for adjustment of current flow in such a bond is as follows (See Figure 40): Place a copper-sulphate half-cell electrode in contact with the soil equidistant from each line between their points of nearest proximity. Excavation may be necessary to properly place the electrode. A temporary bond is then installed and current allowed to flow for several hours, after which the pipe-to-soil potential is observed on the foreign line with the cathodic protection first on and then off the protected line. If the pipe-to-soil potential on the foreign line is higher when cathodic protection of the other line is on than when it is off, or vice versa, the resistance of the bond should be adjusted until no change occurs. This condition is accepted as indicative of no current flow through the soil at the point of crossing.

The current flow to be expected through an adjusted inter-line bond will depend, for the most part, upon whether the lines are bare or coated. With both lines bare the current flow through the bond will be at a maximum; with effective coating only on the protected line the current will be less, and with effective

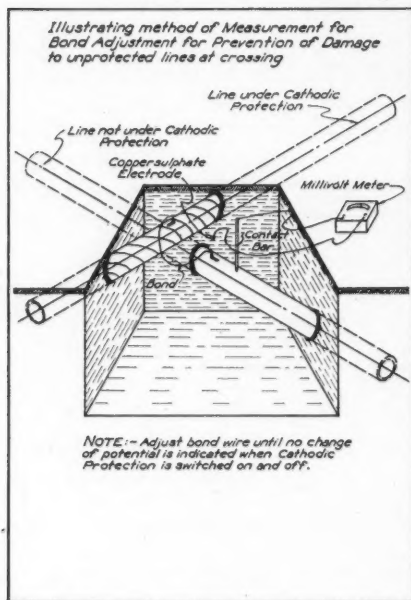


Figure 40—Method of measurement for bond adjustment for prevention of damage to unprotected lines at crossing.

coating on both lines the current will be a minimum. These conditions are illustrated in Figures 41, 42 and 43.

### Pipe Coatings

The desired properties of pipe-coating materials, in their order of importance, are:

- a. Good electrical insulation,
- b. Low moisture absorption,
- c. Insolubility in hydrocarbons,
- d. Inertness to soil chemicals,
- e. Retention of form under soil pressure, and
- f. Ease of application.

(a) When coating is to be the sole means of corrosion prevention, good insulation is of prime importance to prevent metallic ion escape and associated local current flow

from the pipe surface. Insulation also reduces the amount of current required for satisfactory cathodic protection.

(b) Moisture absorption by coatings reduces their insulating properties, and whenever the moisture content is sufficient, an electrical path is established through the coating to start corrosion. After such starts, and corrosion products occupy more volume than the original metal, this expansion breaks the bond between pipe and coating and allows extension of the corroding surface.

(c) Coatings which dissolve in crude oil or other hydrocarbon derivatives are subject to destruction where soil has been contaminated

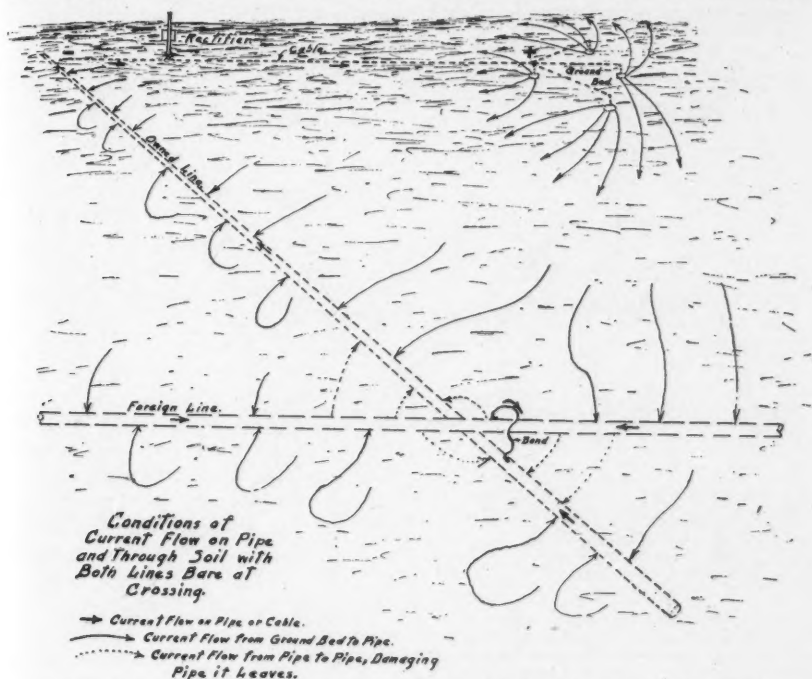


Figure 41—Conditions of current flow on pipe and through soil with both lines bare at crossing.

by them, or by their escape through microscopic leaks which sometimes occur in pipe welds. Oil-soaked soil is encountered frequently along existing lines where corrosion has caused leaks. It is most desirable to maintain effective coating along these leak sections by subsequent treating. Failure of coating along sections under cathodic protection will either reduce the degree of protection or require an increase of current to maintain the desired effect.

(d) and (e) Coating materials must be inert to reaction with normal soil chemicals, or their ultimate destruction will result. They must

resist deformation by soil pressure if uniform coating thickness is to be retained.

(f) Coating materials require special equipment for application and for preparation of pipe surfaces before being applied. Each item of equipment also requires personnel for operation. The more economical coating materials of desired properties usually are those which require the least equipment for preparation and application. A reduction in hazard to personnel will follow if satisfactory coatings can be developed which may be applied at lower temperatures than present ones; however, it is the writer's experience

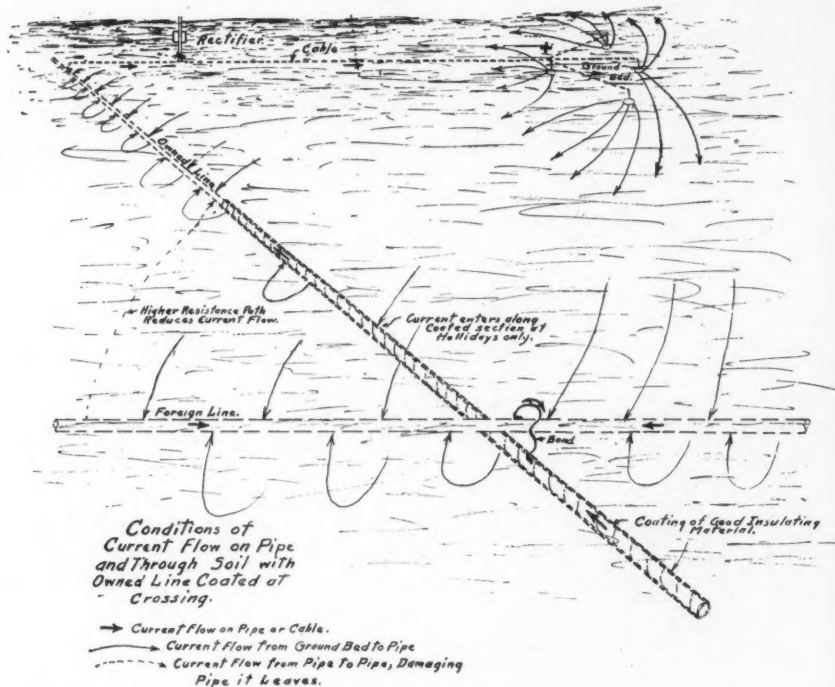


Figure 42—Conditions of current flow on pipe and through soil with owned line coated at crossing.



that available cold-application coatings are not effective.

### Types of Coatings

A general classification of coatings in current use is:

- a. Asphalt enamel,
- b. Coal-tar enamel,
- c. Mastic Coatings,
- d. Greases,
- e. Plastics, and
- f. Concrete.

(a) Asphalt for pipe coating is manufactured in many grades, but those giving best service are the highly-oxidized grades with softening points around 200° Fahr. Such materials have good resistance to deformation. However, they will become softened and even dispersed

when exposed to oil-soaked soil.

(b) Coal-tar enamels are produced in many grades, but those most satisfactory for pipe coating have a softening point around 200° Fahr. They are slightly less resistant to deformation than asphalt, but are not soluble in crude oil or its products.

(c) Mastic coatings are composed of inert materials such as sand, fine gravel, asbestos and similar ingredients mixed with and bonded together by suitable asphalt or coal tar. This mixture is applied to the pipe surface while hot by passing the pipe through machines designed to give continuous coverage and

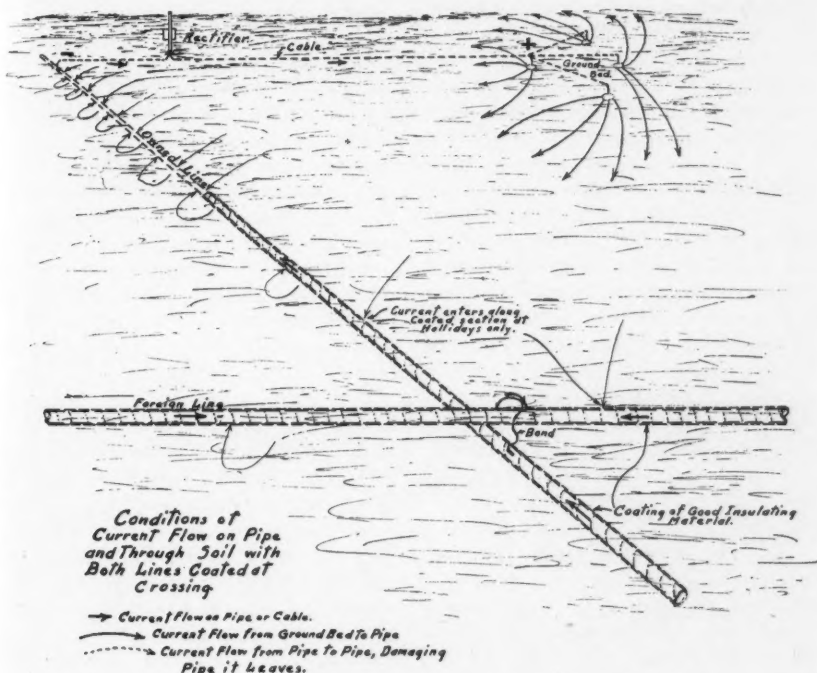


Figure 43—Conditions of current flow on pipe and through soil with both lines coated at crossing.

control coating thickness. Coating thickness on small diameter pipe is around  $\frac{3}{8}$ " with increase in thickness for larger diameters.

Mastic coatings with asphalt binder have good characteristics in resistance to abrasion and deformation under pressure but are subject to deterioration when exposed to crude oil or its distillates. Mastic coatings with coal-tar binder have been produced but further development is required to obtain the desirable properties found in asphalt mastics. However, the coal-tar binder eliminates the rapid deterioration by crude oil and crude oil distillates.

(d) Greases and grease compounds, which basically are of crude oil petrolatum, are highly permeable to underground moisture and are soluble in crude oil. Moisture absorption or oil dilution reduces their electrical resistance and protective properties. These preparations tend to distribute corrosion evenly over the entire anodic section, which extends the time for the first evidence of corrosion until the entire section requires complete replacement. Thus a serious failure may occur instead of merely a few pit-hole leaks. Inhibitor chemicals added to grease coatings assist in reducing corrosion until the absorbed moisture causes their dispersion in the soil. The removal of grease coatings from pipe for subsequent application of hot-bitumen must be complete.

(e) The plastic coatings for pipe applied to date have given wide variations in results, so no definite statements are possible. Most of them have been produced in the form of wrappings for use with a bonding material or with other

types of coating between them and the pipe. In general they decay in contact with the soil, and the decay products may introduce additional corrosive substances adjacent to the pipe. Where soil chemical ingredients are comparatively inert, plastics will have a better chance of survival and should be less likely to accelerate corrosion when coating decomposition occurs.

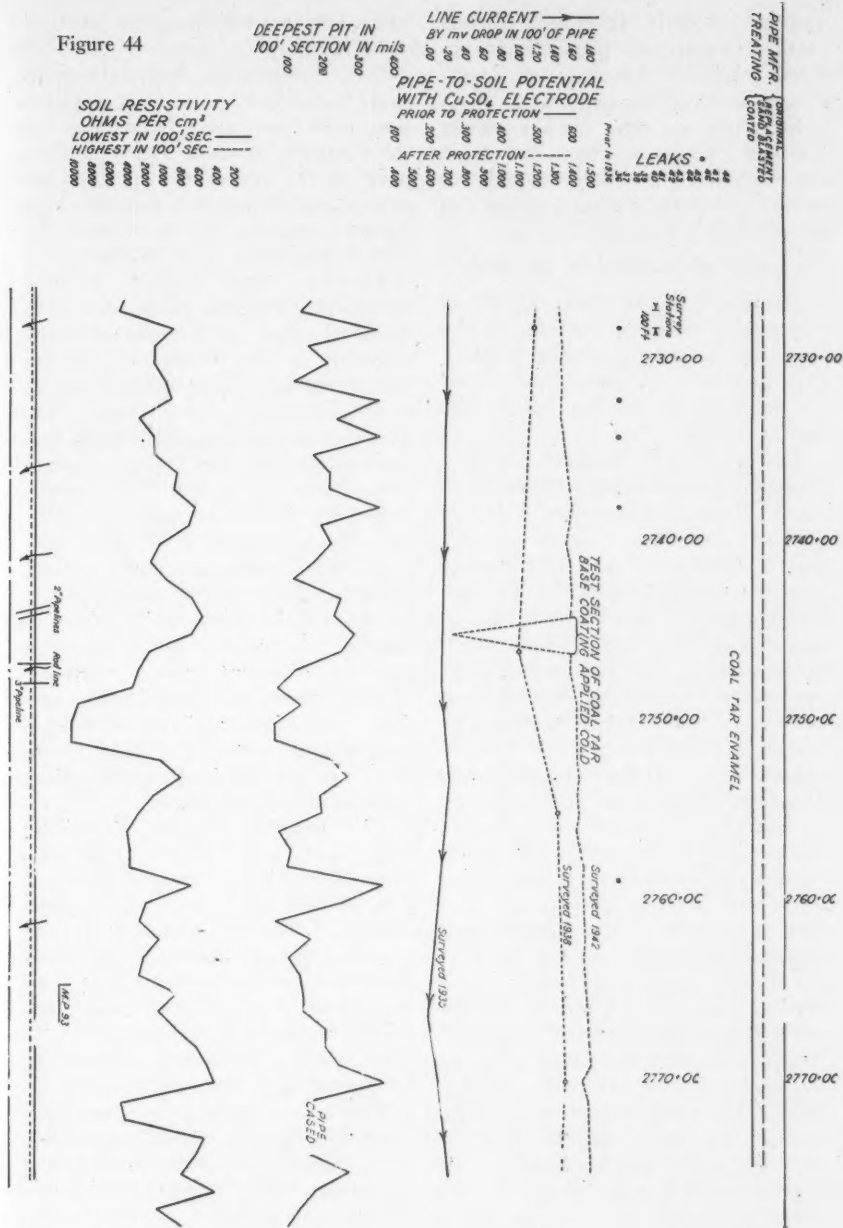
(f) Concrete has been used extensively as a coating by some companies, but most of them have abandoned its use because of its tendency to check and crack with age. These symptoms result from temperature and moisture variations that cause pipe flexure and soil movement.

### Application of Coatings

Bitumen and grease coatings usually are applied with protective and/or reinforcing wrappers. When embedded in the coating material, such wrappers serve as reinforcement. When applied to the surface they act not only as reinforcement but also as protection from soil action or stress. Wrappers applied to the surface of hot coatings before cooling are termed "bonded wrap"; those applied after cooling are termed "unbonded wrap."

Wrappers composed of organic fiber decay rapidly in soil and are highly conductive to moisture before decay sets in. Numerous inspections of pipe with fiber-reinforced bitumen coatings have revealed surface corrosion having the pattern of the reinforcing wrapper. Wrappings should contain the highest permissible percentage of materials inert to soil. Asbestos is most commonly used, but organic fiber is added to give the desired strength for han-

Figure 44



dling. A recently developed fibrous glass wrapper has possibilities because its basic materials are inert; it is non-hygroscopic, and it is lighter and stronger than asbestos wrapper. Organic paper wrap is often applied over other wrappers to protect the latter during hauling and handling in the trench.

### Testing of Coatings in the Field

"Holiday" is the term applied to a defective area of coating. If the full value of coating is to be realized, it is necessary to detect and repair all holidays in coating before the line is buried.

The detection of holidays is accomplished by impressing a 60-cycle or other alternating potential between pipe and coating surface of approximately 4,000 volts per 1-32-inch of bitumen coating thickness. The potential source must be constant to assure a uniform test, and the maximum current flow in the high-voltage circuit should be limited by a resistor to 7 milliamperes. For such testing one company's corrosion engineers use a 300-watt engine-driven generator delivering 110 volts 60-cycle A. C. to a modified neon sign transformer which produces the required test voltage. If the pipe to be tested is in joint lengths on a rack, one side of the high-tension circuit is grounded to the pipe. If in the trench, the ground connection is made to the soil. In both cases the other side of the circuit is connected through suitable insulated cable to a circular or semi-circular metallic brush or coil-spring device (equipped with an insulated handle) which is passed over the coating surface. The coating surface must be dry at the time of testing. Occurrence of a

spark (or arc) indicates the location of holidays.

Only bituminous materials, with some variations in finished application, have been used as coatings on the company system. Those applied prior to the survey during 1933 included asphalt enamel, asphalt-chromated emulsion, coal-tar enamel and coal-tar solutions. The enamels generally had been applied without wrappers. However, a few short sections of pipe were covered with alternate layers of asphalt enamel and wrapping. All of these coatings were inspected during the survey. The unwrapped coatings which had been in service more than two years were found to be ineffective. Coatings with protective wrappers were in better condition.

Electrical measurements taken along sections of the various lines more recently coated will better illustrate the results to be expected from the different types of coatings. Measurements were obtained as surface potentials and converted to pipe-to-soil potentials. The lines were under cathodic protection during these measurements.

The graphic records shown as Figures 44 and 45 are of two sections of line, one section (Figure 44) was coated with coal-tar enamel during 1936 and exposed to oil-soaked soil from previous leaks with additional surface contamination from an old oil field. The other section (Figure 45) was coated with asphalt during 1940 and exposed to oil-soaked soil from previous leaks.

Pipe-to-soil potentials along well-coated lines will decrease gradually with increase of distance from where protection units are located, and this decrease is normally caused by the

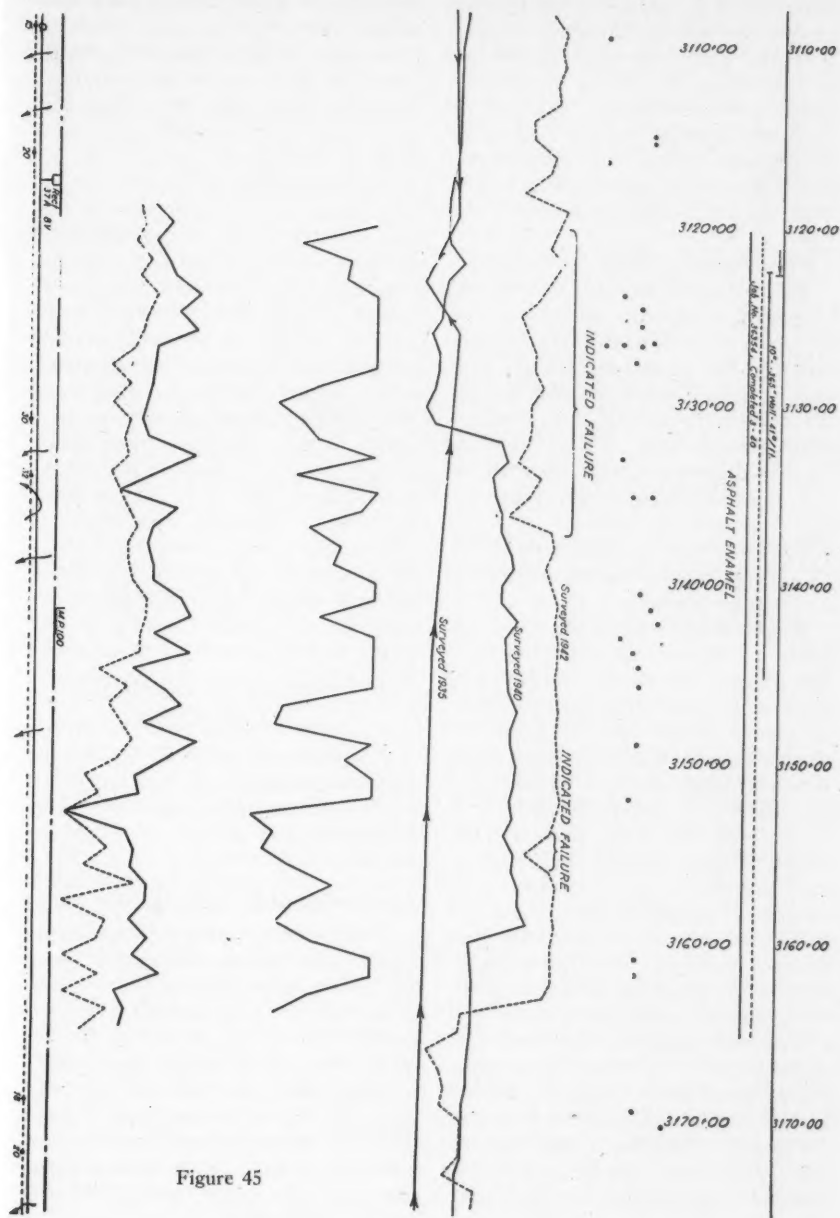


Figure 45

potential drop from current flowing in the pipe metal. A sudden drop in potential at any point along the line is indicative of coating holidays—either voids or failures. If a certain slope of potential has been observed during one survey, and later measurements show variations, it is evident that the coating is deteriorating.

### **Preparation of Pipe for Coating**

This discussion considers only the preparation of pipe surface for application of primer and hot bitumen coating. For successful results, several basic requirements must be met, the most important of which are:

- (a) Elimination of moisture, and of foreign material containing moisture, from the pipe surface; and
- (b) Securing a continuous effective bond between primer and pipe surface.

Requirement (a) is the most important because application of the hot coating vaporizes any remaining surface moisture and causes bubbles or voids—often imperceptible—in the coating through which soil moisture will penetrate and cause corrosion after the pipe is buried.

Surfaces of new pipe can be readily cleaned of mill scale and foreign matter by mechanical cleaning devices in preparation for the application of normal priming material. After a sufficient drying period for the latter, the pipe is ready to receive the hot coating.

Cleaning of old pipe having pitted sections and imbedded corrosion products is more difficult. The only effective means of removing all such products from the rough surface are "shot-" and sand-blasting. The method is expensive, and shot-blast-

ing can be done only at stationary plants. The inclusion of corrosion products, particularly iron oxide, under coatings is not detrimental if the associated moisture can be eliminated; in fact, iron oxide is the base of many metal primers.

Pipe surface primers, diluted by at least three parts of solvent, usually will penetrate most of the corrosion products left in pit holes in the pipe, and such will cause most of the included water or moisture to be exuded to the surface where it can evaporate. The coat of dilute primer, after drying, gives a surface to which the regular primer forms a good bond. Initially the dilute primer may not remove all of the water; however, after it has dried sufficiently to allow application of the normal primer, the surface moisture content will be low enough to prevent damage to coating or to support subsequent corrosion activity underneath.

### **ECONOMICS OF CORROSION MITIGATION**

Expenditures to be made for corrosion mitigation may be considered under (1) those proposed for new lines and (2) those proposed for existing lines.

#### **Economics of Protecting New Lines**

The probable corrosion to be expected on unprotected new lines can be only approximated, either from soil surveys made along the proposed route or by study of experience on existing lines in the vicinity.

Many older lines have been constructed from heavier walled pipe than would have been necessary if covered with a corrosion-resistant coating. The extra metal thickness



was not required to resist internal pressure, and it could have been eliminated if available materials and methods for corrosion mitigation had been incorporated in the line construction. Pipe made from alloy steels, with less weight but with bursting strength equivalent to standard-weight pipe, should save enough in the pipe purchase price and handling expense to almost offset or even exceed the cost of a good coating.

Experience recently demonstrated that 45 miles of 10-inch pipe coated with machine-applied coal-tar enamel and single asbestos-felt wrap were cathodically protected from one rectifier installed at one end of the section with only 5 amperes of current. The coating was applied carefully while the pipe was above the trench, it was then checked with a holiday detector, and then all found holidays were properly patched before the line was buried. Past records indicate that coatings unaffected by oil will have a long life in conjunction with cathodic protection.

From the above it may be concluded that, for maximum economy, new lines should be built of minimum-weight pipe satisfactory for operating pressures, that this pipe should be well-coated when first laid, and that cathodic protection should be applied as soon as practical thereafter. Such construction gives promise of a line with long service life, reasonable assurance of continuous operation as far as corrosion is concerned, and an eventual pipe salvage value nearly equivalent to that of new laid pipe.

### Economics of Protecting Existing Lines

The principal factors to be considered in determining the survey time and extent, and total expenditures justifiable for corrosion mitigation on an existing line will include several factors which warrant individual consideration on each proposed project. The relative importance of these factors may change by reason of circumstances. They are:

#### Service Requirements:

- a. Required life
- b. Required continuity

#### Probable Unprotected Costs:

- c. Leak frequency and distribution
- d. Leak costs
  1. Temporary and permanent repairs
  2. Loss of commodities
  3. Damage and liability
- e. Salvage value of pipe

These several factors are each discussed briefly in the following sections:

### Service Requirements

a. **Required Life:** The probable required service life of a line will influence determination of the degree of protective measures needed, viz., a line with a short required life would need only sufficient protection to keep it operable for that period; conversely, one with a long required life should have measures applied that will remain effective over any desired period of time.

b. **Required Continuity of Operation:** Continuity of operation becomes a factor as follows: When the line is operating at maximum capacity, a shutdown (resulting from corrosion) causes not only a repair expense and a loss of transportation revenue, but also possible losses irrecoverable to shippers or to those receiving the transported oil. When the line is operating at reduced ca-

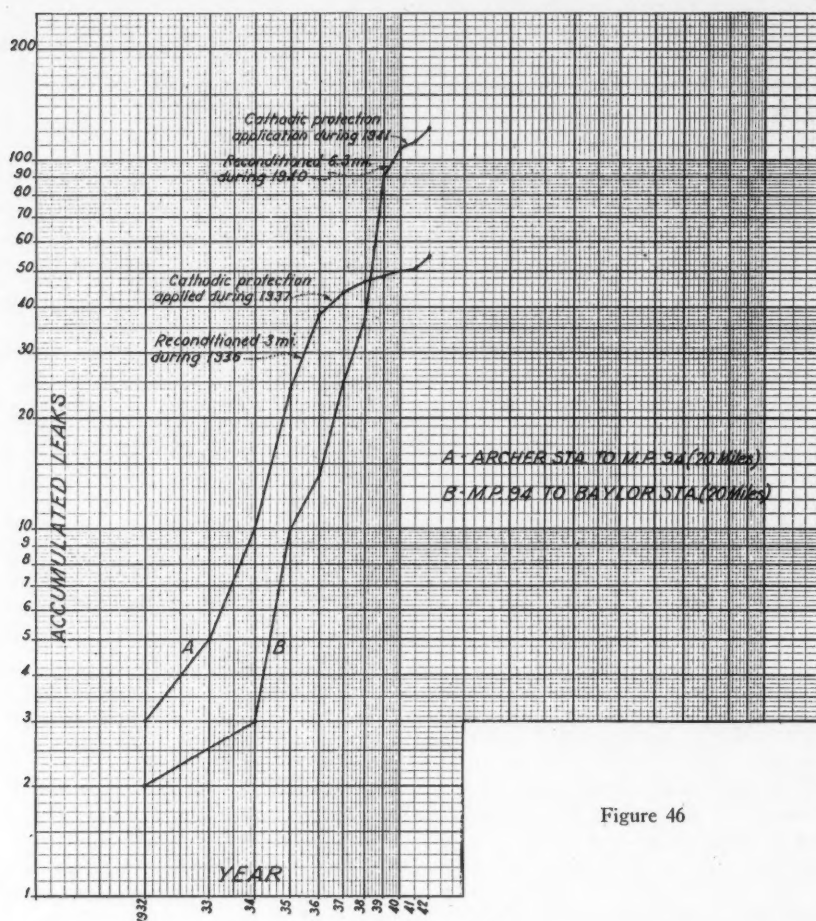


Figure 46

capacity, the interrupted delivery probably can be made up afterwards by increasing the pumping rate. Under the first condition the factor may be of major importance and necessitate corrosion mitigation; however, under the second it may be only of minor importance.

#### Probable Unprotected Costs

c. Pit-hole Leak Frequency and Distribution: Corrosion pit-hole

leak frequency has been found to follow a mathematical series, the sequence of which varies on different lines and with respect to location along a single line. Future frequency can be predicted with reasonable accuracy after a few pit leaks have occurred on a line or a section thereof; however, this accuracy decreases as the length of line is shortened.

Curves plotted on logarithmic cross-section paper with accumulated pit leaks as ordinates, and time in years as abscissas, will result in or approach a straight line as long as no mitigation measures are applied. Such curves may be extrapolated for a few years and the number of probable pit leaks predicted with a reasonable degree of accuracy. The curves plotted on semi-logarithmic cross-section paper with accumulated pit leaks along the logarithmic scale and time in years along the equi-division scale will give sufficient accuracy for practical purposes. A comparison is illustrated in Figures 45 and 46.

The formula for predicting pit leak frequency is:

$$R = bT^n$$

where R = Accumulated leaks due to corrosion

b = Intercept of curve on the R axis, which is the value of T when T is one year

T = Age of line in years

n = Slope of curve

The probable future pit leaks indicated by curve extrapolation serve as an index of future expenditures required for repairs and corrosion mitigation measures associated with these leaks.

Corrosion survey data are a major supplement to leak records. They are of special importance when leaks have not yet occurred and where corrosion mitigation measures are contemplated. These data will indicate areas of probable leaks and their relative distribution, and allow prediction of the extent of line requiring immediate or eventual reconditioning.

d. Cost of Pit-hole Leaks: Since the pit-leak curve may be extrapolated to predict the probable leaks

for a few succeeding years, if the eventual cost of individual leaks is known, it is possible to estimate the probable total cost to be expected on any section of pipe. The elements of the eventual cost are itemized below:

1. Repairs: The cost of pit leak repair includes (a) expenditures made at the time of emergency repair and (b) subsequent expenditures for permanent repair. The first type includes those incurred by repair crew to get to the leak, excavate for it and make temporary repairs by installing a patch held in place with clamps. Permanent repair to secure the patch to pipe usually must be made at a later date after evaporation of escaped fluids permits safe welding at the site.

When a number of pit-hole leaks have occurred in a small area of pipe, it becomes necessary to recondition the pipe or replace it. This cost should be included as part of the eventual leak cost because, if no leaks had occurred, the expenditure for reconditioning would not have been made. Company records show eventual cost of individual cost of individual pit leaks repaired by spot reconditioning to be between \$500 and \$600 each.

2. Loss of Commodities: Losses of commodities through corrosion leaks will vary in value according to kinds of oil transported (e.g., crude oil may be worth \$1.25 per barrel and gasoline \$2.50), so higher values of commodity will correspondingly increase the need to consider this factor. Through some pit leaks practically no fluid may escape; however, in certain

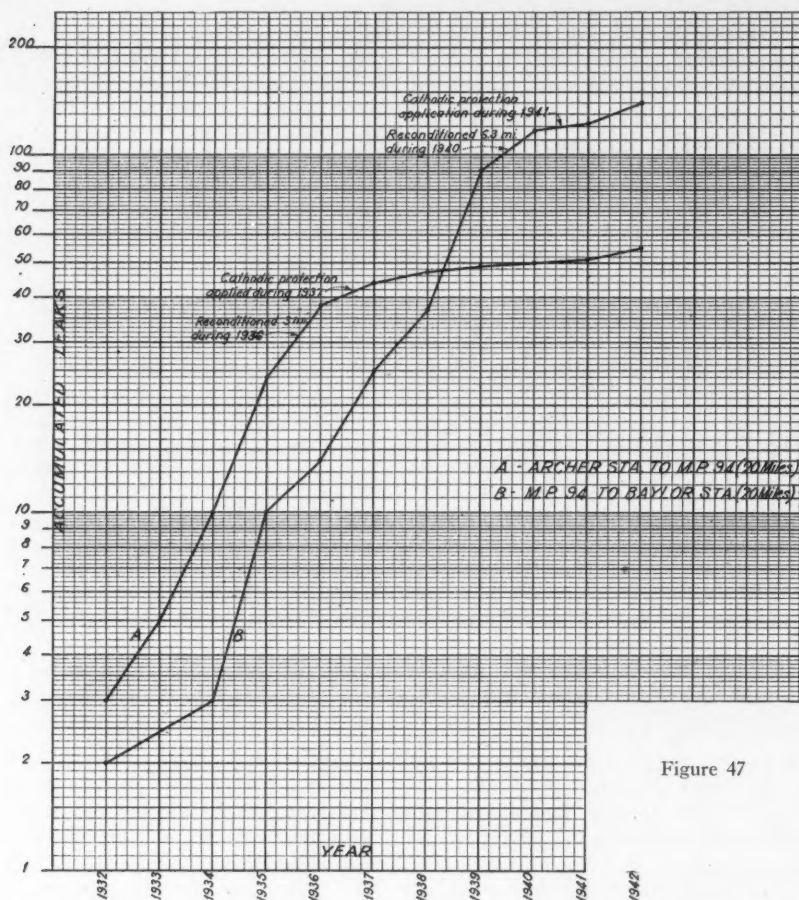


Figure 47

highly-colloidal clay areas where the soil cracks below the surface level on drying, some leaks—often not discernable at the surface—have lost several hundred barrels daily prior to their discovery.

3. Liability and Damage from Corrosion Leaks: Liability and damage losses are not accurately determinable, but an average can be obtained from past records. In sparsely-settled, uncultivated ter-

ritory the probable cost will be low. In highly-cultivated ground, suburban tracts and municipalities the probable cost will be high and increase the justification for corrosion mitigation in those areas.

e. Salvage Value of Pipe: Salvage value at the termination of pipe's economic life is a minor factor; however, if the pipe is to be relaid, there will be an appreciable saving if its

surface does not require abnormal cleaning and reconditioning.

When the required service has been defined, and the probable costs of obtaining this service with an unprotected line have been estimated, then an approximation can be made of the expenditures justified for corrosion control. This justified amount should be expended so as to give promise of the best returns over the period of required service life, a consideration which leads to choice of the most practical and economical method of protection.

### Choosing Methods of Protection

The most practical methods of securing desired results are:

1. Rehabilitation of corroded pipe by electric welding to replace lost metal in deep pit-holes; the application of additional plate metal where necessary; and the replacement of irreparable pipe.
2. Application of coating to the entire line or to sections where surveys have indicated the need.
3. Application of cathodic protection, this to include all coated sections unless future estimated life is less than five years.

(1) Rehabilitation may be done with two objectives. First, if coating alone is used as the protective measure, to restore metal to the pipe surface in quantities to allow for subsequent corrosion which most probably will occur. Second, where cathodic protection and coating are to be combined to give an extensive service life, to restore only a minimum of reduced metal before the coating is applied.

(2) Only when the required service life is short, application of coating to short sections of line is justi-

fied. When the justified expenditure is sufficient and the required service life is between five and ten years, it usually is best to install "galvanic anodes" to augment the coating protection. If lines have a required operation life of more than ten years, they should be coated from station to station and provided with cathodic protection by units at stations.

(3) Cathodic protection may be applied to bare or poorly-coated lines, but the costs of installation, power and maintenance of the larger number of units then required may approach or exceed the cost of coating plus costs of installing and operating fewer units. Location of these units at stations permits regular inspection and assures better continuity of operation.

With a knowledge gained through experience of the relative merits of the above-described methods, an estimate can be made—within the justified expenditures—of the cost of the method or combination of methods most applicable for the conditions in each individual problem. As above stated, proper protective measures result in reduced maintenance cost, curtailment of commodity losses, better continuity of operation, and higher salvage value of recovered pipe.

### SUMMARY

Corrosion of pipe lines and other buried structures is caused by electric currents which flow from metal to soil and electrolytically reduce the metal. Such currents may originate locally from chemical action in Nature's electrochemical cells or, occasionally, may "stray" from direct-current generating stations. Those from natural-cell action vary in in-



tensity and corrosiveness with local soil compositions, moisture contents and pipe surface conditions.

The electric forces associated with corrosion are detectable with suitable instruments that permit its location and relative severity to be generally determined on existing pipe lines by surface tests, i.e., without excavation. With the aid of these test data and pit-hole leak records, the rate of its future ravage can be approximately predicted. Less conclusive estimates of corrosion to be expected on proposed new lines can be made also from surface tests along the route.

Corrosion can be retarded or prevented by reducing or reversing the injurious pipe-to-soil current flows. In order of increasing effectiveness this can be accomplished by: (1), application of current-resistant pipe coatings; (2), establishment of soil-to-pipe counter currents from either (a) buried galvanic anodes or (b) external direct current supplies; and (3), combinations of coatings and counter-current protection. Coating alone has but a limited effective life. Counter-current protection without coating is often prohibitive in cost. The two in appropriate combination are most economical and effective to give pipe lines their required service life.

Corrosion is the prime factor in the cost of line pipe service, and must be reckoned with as well in station underground structures. When the years of required service of a line are known, several factors can be evaluated to determine how much should be spent on corrosion prevention facilities to effect a minimum over-all cash outlay for capital

construction (less salvage credits), line maintenance, and losses—which latter include lost commodities, lost transportation revenues, inconveniences to shippers and refiners, and local leak damage.

Steps to arrest corrosion of existing pipe lines should be taken before abnormal maintenance costs are incurred. The lowest over-all will result if preventive facilities are installed under a comprehensive program rather than piecemeal. Protective facilities on new lines should be planned and installed when the line is constructed.

Inasmuch as the local soil and pipe conditions which cause and prevent corrosion follow the patterns of electrochemical cells, a working knowledge of cell actions and experience with their application is a practical requirement for those who would survey corrosion, interpret results, and choose and design protective measures. This report aims to give the layman a general knowledge of the principles underlying corrosion and the prevention practices of the corrosion engineer.

### Acknowledgement

The author is indebted to many engineers engaged in the field of corrosion mitigation whose published articles and papers have contributed much to such advancement as has been made and for some items of technical data incorporated in this manual.

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Author's Note: Concentration cells referred to in this manual are not salts of the metal involved but are salts normally found in the soil.



# Corrosion Problems in the Petroleum Production and Pipe Line Industry

*By Walter F. Rogers*  
Gulf Oil Corporation

THE business of producing and transporting crude oil requires the use of thousands of tons of steel, most of it in the form of tubular goods. Corrosion losses are an appreciable item to each of these branches of the oil industry and it is difficult to determine which suffers the greatest economic loss. For the pipe-line side there are approximately 150,000 miles of trunk lines in service. These have an approximate equivalent 6-inch pipe size and a weight of 7.5 million tons. On the production side there are 400,000 oil wells. These have an approximate average depth of 3,000 feet and each has one full and one partial string of casing. In addition, in most cases each has a string of tubing and a string of sucker rods. The weight of this equipment approximates 30 tons of steel per well or 12 million tons total.

Although the corrosion problem is of great economic importance to each of these portions of the industry the pipe-line branch has shown much the greater interest in the subject and in return has reaped the greater rewards. By contrast it is difficult to understand the failure of the oil producing people to invest an appropriate amount of time and money in a subject as costly as oil well corrosion.

Perhaps one reason for the large amount of work done on the subject of soil corrosion is due to the stimulus of competitive investigations

brought about through a series of group researches on the subject. In this work the studies of the soil corrosion section of the Bureau of Standards and the pipe coating studies of the American Petroleum Institute have played important parts. The soil corrosion tests of the Bureau of Standards under the direction of Mr. K. H. Logan were started in 1922. The tests consisted of ferrous pipe samples buried in 47 locations scattered over the United States. This work became the focal point for many studies on the general subject of soil corrosion. The results of these individual studies were usually presented at the five soil corrosion conferences held under the auspices of the Bureau of Standards. While the great proportion of these papers are of doubtful scientific value there is little question but that in the main much was learned about the subject. The main problem attacked in these studies, however, i.e., a simple positive way to predetermine the corrosivity of the soil at any given point, is as far from a solution as when the investigation was first made.

Another important group research was the American Petroleum Institute pipe-line coating study. This work required ten years for completion and an expenditure of many thousands of dollars. At the inception of these tests pipe-line coatings on the market were legion in number and in qualifications. The

A.P.I. tests went far in demonstrating to both seller and purchaser what pipe-line coatings could be expected to do and what they would not do. It resulted directly in removing many coatings from the market which while of little or no value were enjoying good sales at the start of the test.

The most important development from all this work was that of electrical protection. The art of this method of controlling corrosion has been known to the scientific world for many years. Its first practical use for the pipe-line industry developed on the Gulf Coast and its use spread rapidly after its presentation at the 13th annual meeting of the American Petroleum Institute at Houston, Texas, in 1932. The pipe-coating tests of the A.P.I. had shown pipe coatings to have the inherent weakness of exposing areas of metal to the soil at points of soil penetration or application holidays. The ability to seal these areas economically with electrical protection has given a great impetus to the double use of coatings and electrical protection to insure that there be no corrosion attack by soil to buried pipes. Today with the tools of electrical protection and pipe-line coatings of proper composition the corrosion engineer can guarantee complete cessation of soil corrosion of buried pipe.

Pipe lines engaged in handling sour crude oils developed internal corrosion problems during the depression years and this problem appeared for a time to be one of the first magnitude. Corrosion trouble from the handling of sour oils has been common for lead lines in sulfide fields since the first sour oils

were produced. This particular rapid corrosion rate has been associated with lines of this type due to the fact that they often are idle, allowing water associated with the oil to settle to the pipe bottom and due to the air which could sometimes enter such lines through the line emptying itself when discharging oil by gravity or simply through reaction with the oxygen which dissolved in the oil by virtue of being in contact with it in open stock tanks.

Trunk lines handling sour oils have, on the contrary, been rather free of internal corrosion difficulties. During the depression years the main oil lines from West Texas developed serious internal corrosion. The only apparent clew to the trouble lay in the greatly reduced throughput of the lines as compared with their designed capacity and initial pumping rates.

Studies were made of the relation of crude velocity and pipe size to the ability of water to remain dormant on the pipe bottom. The results showed that when the oil velocity approached 4 to 5 feet per second water would not settle on the pipe bottom but is picked up and carried along with the stream. At velocities appreciably less than this the water settles to the pipe bottom and remains in contact with the steel pipe, resulting in pitting, of the order of 0.100 inches per year. Sour oil lines which operate at these high oil velocities are free of internal corrosion troubles unless they contain pockets at welded or screw coupled ends where water can settle out of the oil stream. In such cases the pockets or other traps must be cut from the line to elimi-

nate them as sources of internal leaks.

Where the pipe line cannot be operated at high velocities the majority of the time it is necessary to use other means to remove the water from the pipe interior. Rubber disc swab scrapers have been found to be an answer to this problem and can be used with complete success if the line is one of continuous surface available for the rubber disc to contact.

Other methods than the two described are necessary for such lines as cannot be kept clean by velocity or scrapers. These are part-time gathering lines, suction lines around pipe-line stations, etc. These are usually low pressure lines and corrosion-resistant pipe such as asbestos-cement pipe may be used. This pipe is made for 200 p.s.i. pressure which is sufficient for most lines of this type. The couplings are of the same corrosion resistant materials as the pipe and thereby present no joining difficulties from corrosion.

The products pipe-line industry, handling materials such as gasoline, kerosene, butane, etc., started business without any indication that internal corrosion would become a factor. Much to the surprise of the corrosion engineers in this industry these pipe lines rapidly developed severe tuberculation from corrosion attack. This tuberculation increased the friction factor of the lines to such an extent that the daily pumpings fell in some cases to 65 percent and 75 percent of the designed throughput. Such a reduction in the pumpings affected seriously the earnings of the pipe-line companies. It has been found that although the change in the pipe fric-

tion factor is serious, the rate of loss of the pipe wall is not sufficiently rapid to be of major concern. An excellent symposium on this subject was held at the 24th meeting of the API in Chicago, November, 1943. This symposium shows the remedies taken at that time by each of the major products pipe line companies. Fortunately the industry has met and solved this problem. This is most successfully done by either of two water soluble inhibitors. One is the use of sodium nitrite, a patented process, and the other is the use of sodium chromate. Experiences given in the literature with pipe lines combined with unpublished laboratory work show that for pipe-line waters of less than 1,500 p.p.m. total solids and at pH values above 8.0 that two percent of either of these materials in the effluent water gives almost positive protection. The use of scrapers with these inhibitors is usually resorted to although their use may be superfluous after the pipe line is cleaned of the scale formed before treatment was started.

It might appear from the foregoing that the pipe-line business has successfully solved all its corrosion problems. Such is not quite the case. There is yet no adequate remedy for the continued loss of pipe-line storage tanks from the handling of sour oil. The undersides of the decks, the rafters, the top side sheets and the bottoms of these tanks are subject to a high rate of corrosion. The decks are penetrated in 18 to 24 months and re-roofing and general repairs are required in 36 to 48 months. The bottoms can be repaired by installing a 4" to 6" concrete slab. The deck and other

portions in the vapor space are usually repaired by painting. The paints used most generally are coal-tar plastics applied in several coats. The success of these coatings depends entirely upon their application without holidays and to a thickness not less than 0.030 inches. The application of these coatings to an area as large as 55 or 80,000 barrel deck in a dark, poorly lighted area at temperatures frequently over 100°F. decreases the probability that a good job will be done. Either more corrosion-resistant metals or successful coatings of fool-proof application should be developed. When either is done present-day methods of handling this problem will be discarded.

The corrosion problems of the production business cannot be discussed in the same manner as that of the pipe-line business as there is no similar record of problems encountered and successfully met. When discussing oil-production corrosion problems, the field is usually divided into two groups. One group consists of the non-sulfide wells while the other is the sulfide wells. This division is based upon the general fact that sulfide wells show greater corrosion difficulties than do non-sulfide wells, although some of the latter produce highly corrosive fluid.

As stated earlier, the oil-production industry has not spent any great amount of time or money on this problem and there are few items regarding it in the literature. One of the earliest publications on the subject is the 1925 Bureau of Mines Bulletin 233, "Protection of Oil and Gas Field Equipment Against Corrosion," by R. V. and A.

Mills. Since this time a few investigators have worked upon the problem but no great changes in methods for handling it have been developed. In general when a well produces corrosive fluid the corroded equipment is replaced until the time arises when producing the well becomes uneconomic and the well is abandoned. Such abandonment does not, however, usually occur until the well produces a very high percentage of water and little oil. The high percentage of water produced is, of course, one reason for the rapid corrosion rate, although wells producing large quantities of water do not always suffer greatly from corrosion.

One of the main reasons for the failure to learn exactly why oil-well subsurface corrosion takes place is due to the complexity of the problem. A list of some of the more important factors entering into this corrosion reaction may be expressed by the following:

$$C = \phi (T; t; R; V; pH; \frac{W}{O}; S; Cw; W; F; P; M)$$

Where: T = Temperature

t = Time of exposure

R = Electrical resistance of the circuit

V = Fluid velocity

pH = Hydrogen ion concentration

$\frac{W}{O}$  = Water-oil ratio

Cw = Composition of the water

W = Wetting power of the oil

F = Pitting factor

P = Protective coatings such as paraffin from the oil or calcium carbonate from the water

S = Amount of  $H_2S$

M = Metal of construction

In addition to the large number of factors to be reckoned with it must be realized that once a well is selected for study certain of the important factors such as the fluid

temperature and the water-oil ratio may change widely within a short period of time and this in turn may affect the deposition of such natural protective coatings as would be obtained from the wetting ability of the oil or the deposition of paraffin or calcium carbonate. It is no wonder that as little progress has been made with a subject so full of variables. Then, too, another factor which has prevented any great change in the corrosion resistance of materials used for oil wells is that such large tonnages of metal are required per well. The specifications of tubular goods have been changed over the past several years to give greater physical properties to case and tube deeper wells, but no added price is given yet for greater corrosion resistance except for a relatively small tonnage of certain tubular materials, some classes of sucker rods and low-weight materials as polished rods, well pumps, ball and seats, etc. It is doubtful that the producing business could pay an average increased price of 1c per pound premium for all casing and tubular goods to eliminate the corrosion which occurs.

During the past five years a new type of corrosion has appeared in deep high-pressure wells producing from condensate fields. These wells are usually of great depth, have high pressures and produce largely gas with quantities of liquid ranging from 15 to 150 barrels per million cubic feet of gas, the average liquid production being 30 to 50 barrels per million. It has been found

that the tubing, Christmas tree equipment and flow lines of some of these wells have been subject to severe corrosion. Fortunately the corrosion has been detected in time to prevent the wells from blowing out but the danger is always present that a well will get away. This type of trouble has been detected in 10 or 12 fields and considerable interest is being aroused in the subject. A symposium on this type of corrosion was held at the National Association of Corrosion Engineers annual meeting in 1943. The Natural Gasoline Association of America is currently sponsoring a group research project on this subject, financed by a number of oil companies. This work has taken the direction of a fellowship at the Battelle Memorial Institute to investigate the problem. The National Association of Corrosion Engineers is likewise sponsoring an investigation to determine the corrosion resistance of metals and alloys exposed to these corrosive fluids. This work will start with an evaluation of the corrosion resistance of metal coupons exposed in the flow streams of these wells. There is no doubt but that the interest stimulated in the subject by these two investigations will result in the development of valuable information on the subject. They are the first signs of group interest in the subject of production corrosion and it is to be hoped that they will eventually develop the same active interest as followed similar moves for the study of soil corrosion.



## Convention and Exhibition

**T**HE 1946 ANNUAL CONVENTION and Corrosion Exhibition of N.A.C.E. is scheduled for May 7 to 9, at the Municipal Auditorium and Hotel President, Kansas City, Missouri. All technical sessions and the Exhibition will be held in the Auditorium, with committee meetings, the buffet supper and the banquet being staged in the Hotel President.

Growth of N.A.C.E. since its last

annual meeting, held in Houston in 1944, has been so rapid that it is no longer possible to attempt to cover the subject adequately in a single series of sessions. The program has therefore been divided and classified into symposiums, each on an integral part of industry. Two symposiums run concurrently, being arranged so as to permit members and visitors to select sessions which bear most directly on their own problems

### *Program*

#### **TUESDAY, MAY 7**

##### **9:00 A.M.—Committee Meetings**

Policy and Planning Committee

S. P. Cobb, Chairman,

Ebasco Services, Inc.

Technical Practices Committee

R. B. Mears, Chairman,

Aluminum Company of America.

Publications Committee

Dr. Ivy M. Parker, Chairman,

Plantation Pipe Line Company.

Regional Management Committee

George B. McComb, Chairman,

Barrett Division, Allied Chemical & Dye Corp.

Galvanic Anode Committee

M. C. Miller,

Ebasco Services, Inc.

#### **WEDNESDAY, MAY 8**

##### **9:00 A.M.—**

Condensate Well Corrosion Committee

Walter F. Rogers, Chairman,

Gulf Oil Corporation.

All committee meetings scheduled for Hotel President.

#### **TUESDAY, MAY 7**

##### **9:00 A.M.—**

(1) Registration

Foyer, Municipal Auditorium.

(2) Opening of Exhibits

Arena, Municipal Auditorium.

##### **2:00 P.M.—General Assembly**

R. A. Brannon, Presiding.

(1) Opening Address

2:00 p.m.-2:15 p.m.

R. A. Brannon, Humble Pipe Line Company, President of National Association of Corrosion Engineers.

(2) "Romantic Views of Corrosion"

2:30 p.m.-3:15 p.m.

S. J. Rosch, Anaconda Wire and Cable Company.

(3) "The Economic Considerations of Corrosion Problems"

3:15 p.m.-4:00 p.m.

F. A. Rohrman, Kansas State College.

(4) General Business Meeting

4:00 p.m.-4:30 p.m.

Members only.

(5) Adjourn and Visit Exhibits

##### **6:30 P.M.—Cocktail Hour**

Courtesy Exhibiting Manufacturers.

##### **7:30 P.M.—Buffet Supper**

Main Ball Room, President Hotel

R. A. Brannon, Presiding.

"The Challenge of the Atomic Bomb"

Speaker, Professor Henry B. Hass,

Purdue University, Head of Department of Chemistry.



**WEDNESDAY, MAY 8****9:00 A.M.—Water Industry**

H. Arthur Price, Chairman—Department Water and Power, City of Los Angeles.

- (1) "Cathodic Protection as a Corrosion Control Method Applied to Steel Surfaces Submerged in Water"

L. P. Sudrabin, Electro-Rust-Proofing Corporation, Dayton, Ohio.

- (2) "Corrosion in the Water Industry"  
H. Arthur Price, Dept. Water and Power, City of Los Angeles, Los Angeles, California.

- (3) "Designing Water Pipe for Long Life and High Carrying Capacity"  
G. H. Garrett, Thompson Pipe and Steel Co., Denver, Colorado.

- (4) "Corrosion in Cooling Water Systems and Service Lines"  
F. T. Redman, Hall Laboratories, Inc., Pittsburgh, Pennsylvania.

- (5) "Corrosion Problems as Applied to the Interior Water Distribution Systems"

M. P. Hatcher and H. W. Poston, Department of Water, Kansas City, Missouri.

**WEDNESDAY, MAY 8****9:00 A.M.—Electrical and Communication Symposium**

Raymond M. Waggoner, Chairman, Hubbard and Company.

- (1) "Cathodic Protection and Applications of Selenium Rectifiers"

W. F. Bonner, Federal Telephone & Radio Corporation, Newark, New Jersey.

- (2) "Corrosion in and Around Generating Stations"

J. A. Keeth, Kansas City Power & Light Company, Kansas City, Missouri.

- (3) "The Attenuation of Drainage Effects on Long Uniform Structures"  
Robert Pope, Bell Telephone Laboratories, New York, New York.

- (4) "Cable Corrosion in Non-Stray Areas"

J. M. Standring, American Telephone & Telegraph Co., New York, New York.

- (5) "Construction and Ratings of Copper Oxide Rectifiers"

L. W. Burton, General Electric Company, Bridgeport, Connecticut.

- (6) "Cathodic Protection Rectifiers"  
W. L. Roush and E. J. Wood, Westinghouse Electric Corp., Houston, Texas.

**WEDNESDAY, MAY 8****2:00 P.M.—Chemical Industry**

Paul W. Bachman, Chairman, Commercial Solvents Corporation.

- (1) "Clad Steel Processing Equipment for Chemical and Allied Industries"  
Everett C. Gosnell, Lukens Steel Company, Coatesville, Pennsylvania.

- (2) "Corrosion by Aqueous Solutions in Absence of Oxygen"  
Dr. N. E. Berry, Serval Corp., Evansville, Indiana.

- (3) "Condenser Tubes of Aluminum Alloys"

Dr. R. B. Mears, Aluminum Company of America, New Kensington, Pennsylvania.

- (4) "Permeability and Corrosion in Protective Coatings"  
Dr. D. F. Siddall, United States Stoneware Company, Akron, Ohio.

- (5) "Application of Carbon and Graphite to Resist Corrosion"  
C. E. Ford, National Carbon Company, Cleveland, Ohio.

**WEDNESDAY, MAY 8****2:00 P.M.—Gas Industry**

Guy Corfield, Chairman, Southern-California Gas Company.

- (1) "The Installation and Protection of Underground Gas Distribution Systems With Pipe Line Enamels"

P. D. Mellon, Canadian Western

Natural Gas, Light, Heat and Power Company, Ltd.,  
Calgary, Alberta, Canada.

- (2) "Magnesium Anodes for the Cathodic Protection of Underground Structures"  
H. A. Robinson, Dow Chemical Company, Midland, Michigan.

- (3) "Use of Fibrous Glass in Underground Pipe Protection"  
J. A. Grand and S. M. Peek, Owens-Corning Fiberglas Company, Toledo, Ohio.

- (4) "Neutralizing Circuit for Elimination of Long Line Current Corrosion"  
Wm. R. Schneider, Pacific Gas and Electric Company, Emeryville, California.

- (5) "Results Obtained From 5 Years of Cathodic Protection on 24-Inch Gas Line Rapidly Deteriorating From Bacterial Corrosion"  
Wm. E. Huddleston, Bartlesville, Oklahoma.

#### 7:00 P.M.—Banquet

Main Ball Room, President Hotel  
R. A. Brannon, Presiding

- (a) Introduction of New Officers
- (b) Speaker, H. Roe Bartle
- (c) Entertainment

#### THURSDAY, MAY 9

##### 9:00 A.M.—General Industry

R. B. Mears, Chairman — Aluminum Company of America.

- (1) "Effect of Paint on Galvanic Corrosion"  
George W. Seagren, Mellon Institute, Pittsburgh, Pennsylvania.
- (2) "Disadvantages of Dissimilar Metals in Equipment"  
T. G. Hieronymus, Kansas City Power & Light Co., Kansas City, Missouri.
- (3) "Maintenance of Oil Field Equipment"  
D. R. Hiskey, Dearborn Chemical Company, Los Angeles, California.
- (4) "Corrosion Ratings for Metals and Alloys"  
H. D. Holler, Research Engineer, Westinghouse Electric Corporation, Houston, Texas.

- (5) "Designing to Prevent Corrosion"  
R. H. Brown and R. B. Mears, Aluminum Company of America, New Kensington, Pennsylvania.

- (6) "Trends in Painting Structural Steels"

William Singleton, E. I. du Pont de Nemours & Co., Philadelphia, Penna.

#### THURSDAY, MAY 9

##### 9:00 A.M.—Oil Industry

Walter F. Rogers, Chairman,  
Gulf Oil Corporation.

George H. Calhoun, Co-Chairman,  
Shell Oil Corporation.

- (1) "Resistance of Some Nickel Containing Alloys to Corrosion by West Texas Crudes"

B. B. Morton, The International Nickel Co., Inc., New York, New York.

- (2) "Down the Hole Treatment of Condensate Wells"

T. S. Bacon, Lone Star Producing Company, Dallas, Texas.

- (3) "Laboratory Studies for Determination of Organic Acids as Related to Internal Corrosion of High Pressure Condensate Wells"

E. C. Greco and H. T. Griffin, United Gas Pipe Line Co., Shreveport, Louisiana

- (4) "Metallurgical Phases on High Pressure Corrosion Problems"

M. E. Holmberg, Phillips Petroleum Company, Bartlesville, Oklahoma.

- (5) "Use of Sodium Chromate for Control of Corrosion in Gas Condensate Wells"

C. K. Eilerts, H. A. Carlson, R. V. Smith, F. G. Archer, V. L. Barr, Bureau of Mines, Bartlesville, Oklahoma.

- (6) "Results of Some Studies of the Condensate Well Problem"

Walter F. Rogers and Harry Waldrip, Gulf Oil Corporation, Houston, Texas.

- (7) "Down the Hole Treatments of Condensate Wells"

Paul Menaul, Stanolind Oil and Gas Company, Tulsa, Oklahoma.

- (8) "Prevention of Condensate Well Corrosion by Chemical Treatment in the Erath Field"  
W. D. Yale, Texas Company,  
Houston, Texas.

#### THURSDAY, MAY 9

##### 2 P.M.—Corrosion Activities of Technical Societies

F. L. LaQue, Chairman—International Nickel Company.

- (1) "American Coordinating Committee on Corrosion"  
Dr. G. H. Young.
- (2) "American Foundrymen's Association"  
J. T. Mackenzie.
- (3) "American Society of Mechanical Engineers"  
S. Logan Kerr.
- (4) "American Society of Refrigerating Engineers"  
R. S. Taylor.
- (5) "The Electrochemical Society"  
R. B. Mears.
- (6) "American Institute of Chemical Engineers"  
R. B. Mears.
- (7) "Society of Automotive Engineers"  
E. H. Dix.
- (8) "The American Society for Testing Materials"  
Carter S. Cole.
- (9) "National District Heating Association"  
Roy M. McQuitty.
- (10) "Technical Association, Pulp and Paper Industry"  
James A. Lee.
- (11) "American Petroleum Institute" (Production Division)  
H. H. Anderson.
- (12) "American Water Works Association"  
H. Lloyd Nelson.
- (13) "American Chemical Society"  
F. N. Speller.
- (14) "National Research Council"  
F. N. Speller.

The Activities Committee has prepared a program of entertainment for the ladies attending the Convention, including a bridge luncheon, a style show, a sight-seeing trip around Kansas City, matinee, golf game and, of course, attendance at both buffet supper and banquet.

In preparing the program for this annual meeting, considerable thought was devoted to the program of increasing the breadth and scope of the Association and to present before all parties interested in corrosion the activities of this Association and the work pertaining to corrosion of other associations. The solution appeared to be division of the program into the symposiums listed. With the grouping of symposiums agreed upon, it was felt that each should present as many papers as possible during the time allotted it. This, in turn, limited the amount of time which each paper might require.

To insure full coverage of each subject, it was agreed that the author should prepare his paper in full, with all necessary illustrations, charts, graphs and other supporting material. He should then prepare, for reading before the meeting, a 15 to 20-minute condensation of his paper. Prepared discussion, based on the complete paper, also is to be presented, together with discussion from the floor. The complete paper, with all material pertaining thereto, is to be published in *CORROSION*.

## Corrosion Abstracts

### ATMOSPHERIC CORROSION

**Atmospheric Corrosion of Iron.** C. P. LARRABEE, Condensed from "Corrosion Handbook," by Electrochem. Soc. in preparation Blast Furnace & Steel Plant, **33**, No. 8, 993 (1945) August.

Under standardized conditions of atmospheric corrosion tests, many combinations of alloying elements in steel produce rust films which improve the corrosion resistance appreciably over that of copper steel. To reduce corrosion losses below the minimum found for certain low alloy corrosion resistant steels, it is necessary to add alloying elements in amounts disproportionate to their value, due to the fact that, under standard test procedure, a loss of weight of 6.5 g./sq. decimeter of most alloy steels is used up in the protective oxide film.

**Corrosion in the Tropics,** G. W. GRUPP, Metal Finishing, **43**, No. 8, 326 (1945) August.

How the Navy Department fights the "big bad wolf" of the Pacific area is described. The atmosphere is full of sulfur compounds due to volcanic formation, and there are periodic oceanic eruptions of hydrogen sulfide. Dust or coral sands in the air hinder formation of continuous protective oxide films, etc. and heavy rains wash them off. Treatment of parts with corrosion preventives is discussed. Mobile apparatus used by the Navy is shown and described. Natives treasure corrosion prevention secrets, such as using dehydrating flowers near tools. Investigation of these is urged.

### BEARING CORROSION

**Causes of Failure in Heavy-Duty Bearings,** L. M. TICHVINSKY, Paper before A.S.M.E., Cleveland, Machine Design, **17**, No. 7, 115 (1945) July.

Principle characteristics of Diesel-engine piston-pin, connecting rod and main bearings are discussed. Main causes of failure are laid to fatigue of bearing metal under high cyclic loads, excessive or insufficient hardness of bearing material, corrosion by lubricating oil, inadequate bond between bearing metal and shell, assembly errors, foreign particles and miscellaneous, such as defective manufacture, extrusion, wiping, etc. The BHN of cadmium base, copper-lead, lead-base and tin-base bearing material is plotted against temperature. Corrosion of a cadmium-nickel bearing was recorded during a pre-trial inspection. Most intense corrosion occurred next to the copper-deposited flange, and it is believed that copper may have acted as a catalyst during the initial running-in period. Bearing was reinstalled and operated for 2258 hours without additional corrosion. Maintenance and performance of precision-type bearings for small engines are also discussed. Pitted bearing surfaces are shown.

**Heating and Failure of Bearings Due to Little Appreciated Causes.** D. B. HOOVER, Westinghouse Electric Corp., Water Works & Sewerage **92**, 297 (1945) October.

Shaft currents in motors and generators may cause excessive bearing wear and resultant bearing failure.

The surface of a bearing which has suffered from bearing currents is covered with pit marks of various degrees often occurring in bands. The shaft itself may also have marks. Bearing currents may be either direct or alternating. These currents are generally developed with the machine but sometimes originate from outside sources. AC current may be caused by magnetic dissymmetry. Magnetism of shaft may cause DC bearing currents. AC bearing currents may best be eliminated by insulating one bearing. DC currents may be reduced by reducing the magnetizing force around the shaft. **Both may be reduced by shunting.** A sparking test is described for detecting bearing currents.

**Corrosion of Lead by Oxidizing Agents and Lauric Acid in Hydrocarbon Solvents.** C. F. PRUTTON, DAVID TURNBULL AND D. R. FREY, Case School of Applied Science, Cleveland, Ohio, Ind. & Eng. Chem. **37**, 917 (1945) October.

The authors conclude from the results of this investigation that no general mechanism for bearing corrosion can be formulated although an oxidizing agent and an acid are generally involved in the process. Denison's proposed mechanism for peroxide involving the formation of an oxide intermediate is validated for oxygen. Rates of corrosion of pure lead by representative organic peroxides in hydrocarbon media containing organic acids are compared. The effect of temperature on the rates is also studied. To evaluate the effective corrosivity of an oil, it is necessary to consider the thermal stability of the oxidizing agent as

well as its chemical reactivity. Evidence is cited to show that oxynitrogen compounds as well as peroxides and oxygen may be among the oxidizing agents present in oils.

## CATHODIC PROTECTION

**Scientific American**, L. H. WOODMAN, **173**, No. 1, 44 (1945) July.

Results of laboratory research and field tests carried out by Dow indicate that use of magnesium cylinders in cathodic protection of underground pipelines will be an effective and economical procedure and offer a substantial market for secondary as well as primary magnesium. Anodes of magnesium alloys have a driving voltage against iron or approximately 1.0 volt, of twice that of zinc, and show no polarization. Costs of installation are relatively low. A service life of 4 years under "average" soil conditions can be expected.

**Cathodic Protection Controls Polarity to Buck Corrosion Current.** L. P. SUDRABIN, Electro Rust-Proofing Corp., Power **89**, 728 (1945) November.

Advantages of cathodic protection when applied to water tanks are presented. Various factors to consider in providing adequate current density are explained. The relationship between current density and dissolved oxygen content is emphasized as well as need for extreme care in properly designing anodes. It is suggested that rectifiers provide the most satisfactory source of current. Data are presented to show the effectiveness of the application to both cold and hot water tanks.



**Control of Pipe Line Corrosion—a Manual. Part I.** O. C. MUDD, Shell Pipe Line Corporation, Corrosion 1, 192 (1945) December.

A manual designed to acquaint the practical engineer with the causes of corrosion and to instruct him in the procedures for detecting and controlling it. Under the types of corrosion the following are discussed: (1) electrolysis, (2) galvanic action, (3) biochemical attack. Details of instruments and procedures for investigating extent and cause of corrosion are given. (To be continued.)

**The Behavior of Zinc-Iron Couples in Carbonate Soil.** T. H. GILBERT AND GUY CORFIELD, Southern California Gas Company, Corrosion 1, 187 (1945) December.

Data on a set of specific tests involving the use of zinc anodes in high carbonate soil which indicate that in the reaction of the anode with the soil, zinc carbonate is formed which stifles the anode and reduces efficiency.

**Electrolysis Surveys on Underground Cables.** L. J. GORMAN, Consolidated Edison Company of New York, Inc., Corrosion 1, 163 (1945) December.

This paper is a description of the survey methods and the methods for analyzing the electrolysis test data to evaluate the severity of corrosive conditions. These tests are grouped under: (1), maintenance surveys; (2), general surveys; and (3), special investigations. The following measures of cable sheath protection are discussed: (1), electrolysis drainage; (2), cathodic protection; (3), tape protected cable, cable grease protection; (4), cleaning and flushing cable ducts; and (5), insulating joints.

## CHEMICAL CORROSION

**The Saboteur of Chemical-Industry Equipment Is Corrosion.** L. G. VANDE BOGART, Valve World, 41 (1944), No. 1, 16-21, J. of Inst. of Metals & Metall. Abs., 12, 184 (1945) June.

The effects of various acids, solvents, gases, alkalis, salts, asphalt, beer, beet-sugar liquor, hydrocarbons, oils, formaldehyde, gelatin, glucose, glue, hydrogen peroxide, mercury, milk, molasses, rosin, shellac, sulphate liquors, sulphur, sulphur trioxide, tar, water, and wine on iron and steel, Monel metal, nickel, red brass, acid-resistant bronze, and aluminum are tabulated. Recommendations are made as to the use of these metals with the various substances named.

**Corrosion Reporter.** Chem. & Metall. Eng'g. 52, No. 4, 171 (1945) April.

A small manufacturer of pharmaceuticals has trouble with Duralon blistering when sprayed on steel, for use in buckets carrying amines, dilute sulfuric and hydrochloric acids, caustic solutions, aromatic ketones, acetic and phenylacetic acids. When this is solved would like to use this substitute for white enamel for Japansco pumps. Stainless steel Type 316 still bottoms corroded when sodium chloride was added to amines or ketones. Sodium acetate was substituted successfully. Except for corrosion at weld points, stainless Type 316 is successful for equipment used in vaporizing glacial acetic acid and phenylacetic acid. Glass nuts and bolts replaced stainless steel and iron as fasteners of a stirrer used with hydrochloric acid, sulfur dioxide and



hydriotic acid. Monel cooling coils in diazotization reactions were more resistant to reagents than stainless steel. In a sulfuric acid plant operated in conjunction with an oil refinery, Type 316 stainless failed in a flue leading cleaned gases out of gas scrubber, in preliminary tests. Haveg has been installed instead. Red brass is to replace steel as soon as it is available in pipe lines handling acid sludge.

**Acid-Resisting Steels for Chemical Plants**, A. RASCH AND R. WEHRICH, *Chemische Fabrik*, **12**, 231 (1941); *Chemical Age*, **1944**, 521, December 2; **1945**, 15, January 6; *Chem. & Metall. Eng'g.* **52**, No. 5, 171 (1945) May.

Practical experience during the 25-30 years that high chromium and chromium-nickel steels have been used in the chemical industries shows that for many purposes plain chromium, chromium-molybdenum, chromium manganese, and chromium-manganese-nickel steels may be employed instead of the customary 18-8. For example, calenders used in the paper industry are produced from chromium-manganese-nickel or chromium steels instead of 18-8. 17-chromium or chromium-manganese-nickel steels are used in the milk industry instead of 18-8. The most important corrosion resistant steels used today in the chemical industries may be divided into 4 classes according to their composition; chromium (17), ferritic-pearlitic structure, magnetic; chromium-nickel (18-8) austenitic, non-magnetic; chromium-manganese-nickel (18-14-1.5) ferritic-austenitic, weakly magnetic; chromium-manganese-nickel (18-5-1.5) ferritic-austenitic, weakly magnetic. Application of each group is

discussed. Chromium steels show good resistance to nitric acid solutions, nitrous vapors, fats, and many salt solutions. They are particularly suitable for solid members such as shafts, spindles, valves and valve seats. The chromium-nickel steels have found their most general application in high-pressure equipment. All the chromium-manganese-nickel steels possess good toughness at very low temperatures. Widely used in place of the 17-chromium steel in the food industry. Application for the low manganese chromium-manganese-nickel steels is limited.

**Result of Improper Boiler Cleaning**, *Proceedings of the Merchant Marine Council of the U. S. Coast Guard, Marine Eng'g & Shipping Review*, **50**, No. 8, 150 (1945) August.

Recent investigation by the Coast Guard in connection with the rapid deterioration of certain internal boiler fittings and tube ends indicated a severe condition of acid corrosion caused by some agent introduced from an outside source. The chemical processes employed in the internal cleaning of the boilers require the use of inhibitors to eliminate reaction between the chemical employed and the metal cleaned. The temperature should be checked because inhibitors lose their effectiveness during use, largely through increase of temperature. Hydrochloric acid is the base for many boiler-cleaning processes. The corrosive action of hydrochloric acid with elevated temperatures increases the activity of the solution. All traces of acid must be removed and the unit should be flushed out with water to which may be added a neutralizing alkali.

**Corrosion Reporter—Rubber-Covered Agitator—Manufacture of Sodium Silicates**, E. C. FETTER, Chem. & Metall. Eng'g, **52**, No. 5, 171 (1945) May.

Description of a rubber-covered agitator which successfully withstands exposure to boiling hydrochloric acid. The saturated zinc chloride solution is shipped in steel drums or in rubber-lined tank cars. Nitric acid is stored in a welded tank made of chromium stainless steel, and pumped through piping made of stainless type 347, using a pump made of 18-8. The manufacture of sodium silicates requires the use of one corrosive material, sodium hydroxide. Installation of a steam coil made of 18-8 in the steel tanks when heated prevents pitting and corrosion.

**The Corrosion of Zinc by Manganese Dioxide** (in Dry Cells), K. ARNDT, Metallwirtschaft, **21**, No. 49, 762 (1942); J. Inst. of Metals & Metall. Abs., **12**, 284 (1945) September.

An investigation of the causes of zinc corrosion in dry batteries showed that this is affected by the activeness of manganese dioxide, the purity of zinc used, and the structure resulting from the method of fabrication of the cups.

**U. S. Pat. 2,387,284, Inhibitor for Carbon Tetrachloride**, E. O. OHL-MANN, The Dow Chemical Co., Pat. Gaz., **579**, No. 4, 579 (1945) October 23.

A method of inhibiting the corrosion of metals by wet carbon tetrachloride in contact therewith, which

comprises dissolving in the carbon tetrachloride at least 0.1 percent by weight of rosin and from 0.001 to 0.1 percent by weight of a primary mono-amine. Test results show effect of inhibitor weight losses of various metals including Monel and stainless steel in carbon tetrachloride.

**The Corrosion of Copper Evaporator Tubes**, H. INGLESANT AND J. A. STORROW, J. of Soc. of Chem. Ind., **64**, No. 8, 233 (1945) August.

Copper heating tubes from a glucose evaporator were examined to determine the cause of their corrosion. The progressive degree of attack along the length of the tubes on the liquor side suggested that the moto-electric (electromotive) effect was the major factor leading to reduction in wall thickness. Tests on a model evaporator confirm this explanation.

**Preventing Corrosion of Copper Heating Coils**, N. A. ALYAVDIN, Legkaya Prom., **2**, No. 5, 25 (1942) (in Russian), J. Inst. of Metals & Metall. Abs., **12**, 283 (1945) September.

Copper heating coils in plants extracting tannin are subject to both internal and external corrosion. The damage can be effectively minimized, as far as external corrosion is concerned, if a metal more basic than copper, e.g., zinc, is inserted in the system so as to reverse the potential. Some practical suggestions are made.

**The (Corrosion and) Use of Metal in the Cider Industry—Inconel, a Nickel Alloy**, G. WARCOLLER AND J. TAVERNIER, Bull. Assoc. Chimistes, **59**, 464 (1942); Chem. Zentr. **114**, No. 1,

2046 (1943); J. Inst. of Metals & Metall. Abs., 12, 218 (1945) July.

To determine the usefulness of Inconel in the cider industry, Inconel plates were exposed to various solutions for 101 days. These were appreciably attacked by 200 mg.-%sulfur dioxide solutions; less by malic and acetic acid (to which they were more resistant than aluminum and its alloys); were quite resistant to conc. solutions of sodium carbonate calcium chloride, and to Javel water. Fermenting cider and must could be kept in Inconel containers without appreciable injury to the metal; the attack on the metal, however, was intensified by higher combined and free acidity in the musts. For instance, must sulphurated with 1 g.-%sulfurdioxide could not be stored in Inconel containers. Corrosion tables are given. According to results of preliminary experiments Inconel is inferior to special steel A.R.C. 2702 and Uranus 10, but superior to Monel because of its greater resistance to corrosion by cider and must, and its use in the cider industry is indicated. Bibliography.

**Corrosion in Hydrofluoric Acid Alkylation.** M. E. HOLMBERG AND F. A. PRANGE, Phillips Petroleum Co., Ind. & Eng. Chem., Ind. Ed. 37, 1030 (1945) November.

Corrosion of all metals tested in hydrofluoric acid service is greatly affected by presence of air or oxygen. Monel metal suffers denickelization in the presence of air. Copper and the 12 chrome stainless steels are very sensitive to velocity. Most metals are greatly affected by rise in temperature. Carbon steel is limited to a maximum of about 150° and

Monel metal to 200° F. Most metals are also affected by aqueous dilution of acid. Cupronickel shows the greatest resistance to aqueous solutions. It is suggested as a good material for heat exchanger tubes. Monel metal has proven very satisfactory as a valve trim material. Plain low carbon steel has proven quite satisfactory under anhydrous conditions at temperatures below 150° F. Certain materials such as Hastelloys A & B, cast iron and high-zinc uninhibited brasses suffer intergranular attack in this service. The failure of screwed fittings at the thread has been attributed to the use of notch sensitive metals such as free-machining and high phosphorus steels plus the reduction in wall thickness resulting from making the threads. It is recommended that heavier pipe be used when screwed connections are unavoidable. Embrittlement is another problem. However, soft unhardened steels have not proven susceptible to this attack. K-Monel appears to be least susceptible of the high strength metals.

**Notes on Use of Copper-Nickel Alloy in HF Alkylation Procedures.** B. B. MORTON, International Nickel Company, Corrosion 1, 228 (1945) December.

Corrosion test data are presented to show that the corrosion of the copper-nickel alloys in air-free solutions is very low in various strengths of HF. The use of these alloys as liners for vessels, as rings and packing and for valves and fittings is discussed. The danger of combining carbon packing with copper-nickel alloys is pointed out. The non-galling properties of S-Monel against

plain monel are advantageous for reconditioning and manufacturing valves.

**Materials for Producing the Atomic Bomb.** K. ROSE, *Materials & Methods*, **22**, No. 4, 1054 (1945) October.

Some of the specific problems met in the purification of uranium and preparation of plutonium for the atomic bomb are discussed, with a flow chart. Companies involved in the solution are mentioned where possible. Thin aluminum sheet was chosen because of its low neutron-absorption power and high corrosion resistance to sheath uranium slugs to protect them against attack from the cooling water, and aluminum was used to pipe the latter. Neutron intensity was controlled in the power pile by boron steel rods moved in and out of the pile to vary the fraction of neutrons available to produce fission. Finding high temperature materials is stated in the Smyth report to be the major problem in the non-war use of atomic energy. However, the first purified uranium cost \$1,000 per lb. but the material cost only \$22.00 a year later. An automobile engine the size of a man's fist and possible use of atomic energy as a heat source are among developments predicted. More than 5000 new and improved products and procedures will be available to industry as soon as released by the government. Some of the latter are: a method of weld checking, for pre-testing pressure vessels for leaks before operation, several improved vacuum techniques, and new treatments of metal surfaces to prevent corrosion.

## CONSTRUCTION MATERIAL

**Clad Steels for Corrosive Service.** H. S. BLUMBERG, M. W. Kellogg Co., *Corrosion and Material Protection*, **2**, No. 7, 11 (1945) April.

Clad steels are defined as those having at least 3 percent of the total thickness consisting of a special surface material. The need for clad steels, general properties of individual backing and facing materials, common methods of cladding welding processes, and testing methods are discussed. Corrosion resistance and other properties of plain high chromium and high chromium-nickel stainless steels and high nickel alloys are discussed in detail, and types used as facing material are tabulated. Welding rods for use in joining clad steels and heat treatments of steels clad with various facing materials are also tabulated and discussed.

**Heat and Corrosion Resistant Steels.** R. W. JONES, Carnegie-Illinois Steel Corp., *Steel Processing*, **31**, No. 8, 489 (1945) August.

Relative importance of various properties for high pressure and temperature applications, particularly in the petroleum industry, are analyzed. Types of stainless steels for different uses are discussed, with welding characteristics.

## COATINGS

**Corrosion - Resisting Plastic Material Applied to Oil-Field Equipment in Place.** E. H. SHORT, JR., *Oil and Gas J.* **44**, No. 33, 59 (1945) December 22.

Field application of plastic coating is suggested for oil-field storage tanks, tubing, pipe, salt disposal sys-

tems, sucker rods, valves, concrete floors, etc. Storage tanks coated at Magnolia, Arkansas, were in excellent condition after 3 months. Internal surfaces of storage tanks require one prime coat and 3 finish coatings. Physical properties of coating are listed as follows: Thickness, 0.003 in. per coat; Film strength, 1400 psi; Film stretch at break, 180-200 percent; Cold resistance, will not crack when bent at 32° F. and will bend around  $\frac{1}{8}$  in. rod at 0° F.; Adhesion, will not blow off in air blasts; corrosion resistance, acids, alkali and salt water; Heat resistance, unaffected at 180° F. Data on tests in numerous solvents are given. Also see *The Oil Weekly* 120, No. 6, 22 (1945) January 7.

**Corrosion Protection of Steel Pipe by Resin Baking Coatings**, Nat. Petr. News 37, No. 49, R-992 (1945) December 5.

Abstract of a paper by R. J. Moore, Bakelite Corp., at the 1945 Fall Regional Meeting of the Federation of Paint and Varnish Production Clubs. Induction heating is presented as a substitute for oven baking in plastic coated steel. The new process gives a more continuous coat in much less time. The article is dipped in the resin bath and then passed through an electromagnetic field which is actuated by high or low frequency current. Such coated pipe is being used for low temperature heat exchangers (220°) and condensing equipment, solvent recovery plants and as a pipe line coating where the smooth surface reduces friction. Diagram for laboratory coating unit is shown.

**Synthetics and Engineered Corrosion Control**. D. F. SIDDALL, U. S. Stoneware Co., Paper before Am. Electropl. Soc., Waterbury & Phila. Branches Am. Electropl. Soc. Monthly Rev., 32, No. 4, 331 (1945) April.

Organic linings suitable for corrosion resistant use are discussed. Reasons for failures of organic substances to resist or prevent corrosion are discussed. An organic lining is broken down if the energy of the corrosive force is greater than the bond energies or strengths that tie the individual molecules or polymers together, and the higher the molecular weight, the more it will resist corrosion. Thermoplastic and thermosetting types are discussed. Compounding ingredients must be added to make a thermoplastic polymer useful as a lining, and the compounding ingredients must be as corrosion resistant as the polymer itself. Choice of process equipment and materials is discussed. Use of synthetic rubber has not been thoroughly explored and in many cases has not been satisfactory as a protective coating. Resins themselves show extreme resistance to many acids and alkalies, but must be compounded to meet physical and electrical requirements. These compounding ingredients determine the length of service of the substance. In general, the use of different types of thermoplastic resins will widen the range of chemical solutions that can be handled. This article very briefly abstracted in December issue of CORROSION.

**Electrodeposition of Vinyl Plastics**. M. BEINLEIB, Paper before Electrochemical Soc., Symposium on



Electro-Organic Reactions. Electrochem. Soc., Preprint 88-6, 47 (1945) October 8.

The amphoteric deposition from organic suspensions of plastics of the vinyl group is presented. Conditions and variables are discussed. Optimum conditions are presented for vinyl chloride and vinylite. Applications are suggested in the fields of corrosion protection of metals, electric insulation, and in the production of thin plastic sheets or thin-walled plastic articles of any desired shape or design. The very resins that show poor solubility characteristics and poor lacquer-forming properties with the usual solvent, are the most resistant to chemicals, both inorganic and organic. Polyethylene, satisfactorily deposited, would be of great interest in protection of metals against corrosion. Saran and vinyl chloride are also very chemically resistant.

**Organic Coatings in the War Against Corrosion.** C. E. ERB, Standard Varnish Works, Corrosion & Material Protection, 2, No. 6, 9 (1945) September.

New synthetic resins and plastic-base coatings, both of the air-dried and baked resin type, have overcome most of the objections to use of organic coatings for unusual conditions. The type and thickness of films formed, preparation of metal surfaces, manner of application, and illustrations of corrosion-resistance of one of Standard Varnish Works coatings, Cortex, in a salt plant are discussed and shown.

**The Electrodeposition of Metals on Plastics.** H. NARCUS, Plating Processes Corp., Paper before Electrochem.

Soc. Symp. on "Before and After Plating," Electrochem. Soc., Preprint 88-5, 29 (1945) October 8.

The main purposes of metallizing a plastic article are to render it a suitable substitute for critical and strategic materials and to produce a finished article with the inherent properties of the plastic in addition to the desired properties of the deposited metal. Tests show that plating increases tensile, impact, and flexural strength of plastic and its resistance to heat distortion. Water absorption is decreased. Because of the absence of electrolytic effects, due to basic metals, a metallic coating on plastic is more resistant to corrosion than when applied to a basic metal. The best commercial method for metallizing plastic is the application to the surface, after proper preparatory treatment, of a highly conductive and strongly adherent bond coat of metallic silver, followed by an intermediate layer of copper and finally a top layer of the desired metal. Direct and optical methods for controlling and measuring the thickness of the silver film are described. Data from corrosion test in synthetic sea water of plated steel and plated plastic test specimens in which the plating sequence was copper, nickel and chromium are tabulated.

**The Substitution of Blackplate for Tinplate in Cans for Fruits and Vegetables.** W. B. ADAM AND D. DICKINSON, Paper before Iron & Steel Inst., Iron & Steel Inst., August, 1945, Adv. Copy, 11 pp.

A study was made of the effect of substituting blackplate ends for tinplate ends in fruit and vegetable cans. Rate of formation of hydrogen



in the cans, of dissolution of iron and tin, and effect on color and flavor of contents were noted. Color and flavor of vegetables were not affected if lacquer protection was adequate, but the situation was unsatisfactory with fruits. Types of lacquer varied in the protection they afforded. Rates of attack of fruits and vegetables on blackplate ends varied greatly and was highest for fruits. Cold-reduced plate was superior to hot-rolled plate on blackplate ends covered with a single roller-coating of lacquer. Phosphating does not reduce rate of internal corrosion and may increase it if the lacquer adheres indifferently to the surface of the plate.

**The Use of a Tin Undercoat to Improve the Corrosion Resistance of Painted Steel.** E. S. HEDGES AND L. A. JORDAN, *Iron and Steel Inst.* (1945) July, Adv. Copy. See also *Engineering* **160**, 505 (1945) December 14.

The effectiveness of tin undercoats on painted steel in retarding corrosion was investigated in a series of tests covering deposits of tin from both alkaline and acid baths, use of flash-melting and oxidizing the tin surface by chemical treatments. Specimens of plain steel, hot-dipped tin-plate and phosphated steel were included. Twelve different paints were applied. Accelerated corrosion tests show that treatment with the electrodeposited tin, especially when followed by use of the T.R.I. (Tin Research Inst.) anti-rusting oxide film adds greatly to the protection afforded by the paints.

**Immersion Coatings.** O. KRAMER, *Metallwaren Industrie u. Galvanotechnik Metal Ind.*, **66**, No. 8, 121 (1945) February 23 (Transl.).

Suitable methods for coating without current, or immersion plating, are described, including gilding iron; copper, nickel, silver, and tin on zinc; gilding zinc; copper, nickel, zinc, tin on aluminum; copper on tin; nickel, zinc, tin and silver on copper.

**U. S. Patent 2,381,778. Process of Producing Protected Metal Articles.** J. M. SCHOONMAKER, JR., Sewickley, AND F. STOCKTON (to Standard Steel Spring Co.), *Patent Gazette*, **577**, No. 1, 265 (1945) August 7.

Method of protecting a ferrous article against corrosion which consists in depositing a continuous coating of nickel of substantially uniform thickness on the article, then applying to the nickel a coating of tin, and then heating at a temperature above 350° F. and below the melting point of tin for a period of time sufficient to diffuse a part of the tin into the outer portion only of the nickel.

**Coating of Steel with Aluminum at High Temperatures.** M. ALFERIEFF, *Genie Civil*, **120**, 139 (1943); *Chem. Zentr.*, **114**, No. 2, 1132 (1943), *J. Inst. of Metals & Metall. Abs.*, **12**, 285 (1945) September.

Before coating steel by dipping it into aluminum at a temperature which is not much higher than its melting point, the steel undergoes a heat-treatment in a special atmosphere; it is deoxidized and partially decarbonized in a nitrogen and hydrogen atmosphere free from water. Between the aluminum coating and

the steel, a layer of  $\text{Al}_3\text{Fe}$  (aluminum ferrite) is formed which improves the adhesion of the coating.

**The Structure of Thin Nickel Foils Obtained by Means of Cathodic Deposition.** A. COLOMBANI AND J. WYART, *Compt. rend.*, **215**, 129 (1942), *J. Inst. Metals & Metall. Abs.*, **12**, 214 (1945) July.

The structure, as shown by x-ray diffraction, of nickel foil of different thicknesses is described, with accompanying electrical properties. The effect of annealing is also mentioned. The electrical conductivity, which between 2200 and 4600 Å. is a function of thickness and temperature, becomes, above that limit, independent of the former quantity.

**Corrosion Protection of Zinc and Zinc Alloys by Non-Metallic Inorganic Coatings.** K. Voss, *Metallwirtschaft*, **21**, No. 49, 754 (1942), *J. Inst. of Metals & Metall. Abs.*, **12**, 286 (1945) September.

Recent patents on the corrosion protection of zinc and zinc alloys by immersion and electrolytic methods (especially those based on chromate solutions), are reviewed, and their salient features discussed.

**Painting of Aluminum and Its Alloys.** A. BEHR, *Paint Manuf.*, **14**, 301 (1944), *J. Inst. of Metals & Metall. Abs.*, **12**, 285 (1945) Sept.

Painting systems for aluminums are discussed; it is suggested that primers should be devised which cause oxidation of the aluminum and hence lead to improved adhesion. Corrosion inhibitors for aluminum, such as the sparingly soluble silicates, organic compounds readily absorbed by aluminum to form protective layers, zinc giving galvanic

protection, and ion-exchange materials, are suggested as unorthodox primer ingredients. The water-permeability of paint systems should be studied specifically. Antifouling paints containing mercury are unsuitable for use on aluminum.

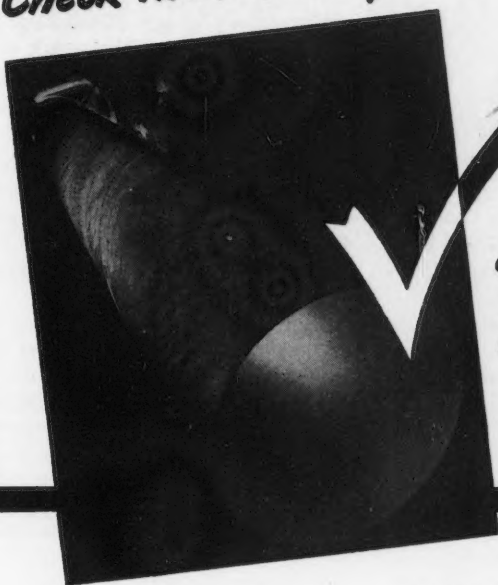
**Corrosion Problems in the Petroleum Industry, 4. Zinc as an Anti-Corrosive Pigment, Some Divergent Views.** A. H. STUART, *Petroleum* **8**, 197 (1945) October.

Experimental work is reported to show that zinc gives protection to steel when it is in close proximity as well as when in contact and that the sacrifice of zinc is less than when in direct contact. The non-protective action of paints containing zinc is shown to be due to the insulating action of the bonding material. A paint made up of graphite, zinc, gelatin and water for experimental purposes showed that with a conducting medium the zinc afforded excellent protection not only to the painted surface, but to a distance of approximately 1 inch beyond the painted surface.

**U. S. Patent 2,389,229. Antifouling Composition.** G. H. YOUNG (to Stoner-Mudge, Inc.), *Patent Gazette*, **580**, No. 3, 402 (1945) November 20.

An antifouling composition for application to surfaces subjected to immersion in sea water and adapted to prevent the attachment thereto of fouling marine organisms while exerting a protective non-corroding action on the surfaces, comprising as the sole film-forming agent a substantially water-insoluble, solvent-dispersed, film-forming organic vehicle having a permeability to water of 5 to 200 milligrams of water per mil of film thickness per square inch

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per 24 hours, and a toxic component which is a condensation product of a mercuric salt and an aromatic compound selected from a group consisting of benzene and the lower alkyl, aryl, and alicyclic-substituted benzene hydrocarbons, together with their hydroxy and halogenated derivatives, the concentration of toxic component being approximately 15 to 50 percent by weight of the total non-volatile content.

**Antifouling Paints; Mechanism of Accelerated Corrosion Under Antifouling Compositions Applied to Steel.** G. H. YOUNG, G. W. SEAGREN and J. ZEHNER. Mellon Inst. Ind. and Eng. Chem. **37**, 461 (1945) May.

This paper is further to a series which has shown that direct and intimate contact with steel can result in materially decreased efficiency of cupriferous antifouling paints, with accelerated corrosion of the steel. The attack is particularly severe wherever the steel is exposed, as at a scratch or mechanical break in the paint film. The suggested mechanism for accelerated corrosion in the presence of heavy metal antifouling paints involves actual deposition of copper from aqueous solution in and under the paint film, and at breaks and similar discontinuities. The acceleration could result from the couple action of these copper desposits rather than from the metal pigments as such.

**Evaluation of Antifouling Paints by Leaching Rate Determinations.** BOSTWICK H. KETCHUM, JOHN D. FERRY, and ALFRED C. REDFIELD. Woods Hole Oceanographic Institution, and ARTHUR E. BURNS, JR. Navy Yard. Ind. Eng. Chem. **37**, 456 (1945) May.

The leaching rate test is presented

as a valuable tool which can be used along with exposure and fouling tests by paint technologists in the formulation and testing of antifouling paints. It is shown that the solution of 10 mg. of copper per sq. cm of paint surface per day will prevent the attack of all marine growths which normally present a serious ship-bottom fouling problem.

**Anomalous Inactivation of Heavy Metal Antifouling Paints.** G. H. YOUNG AND G. W. SEAGREN, *Nature*, **155**, 715 (1945) June 16, *Bull. of the Iron & Steel Inst.* (1945), No. 115, 69 July.

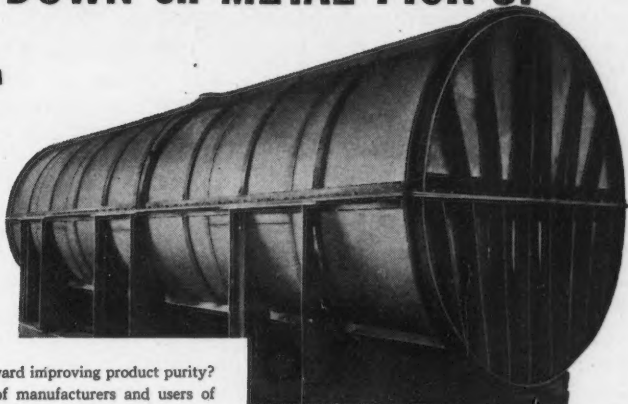
It has been established that cuprous-oxide and metallic-copper antifouling paints when applied over bare steel rapidly lose their antifouling efficiency after about one month's immersion. Tests on panels submerged at Daytona Beach, Florida, indicated that corrosion products on one part of a panel can be washed across the rest of the panel by currents and passivate the antifouling paint over which they pass, thus causing bands of fouling to appear. Tests were also made to determine the effect of the accidental contact of steel bolts or anchor chain against an antifouling paint on a wood hull. Only in the case of non-insulated contact direct to the face of the metallic copper formula was there an appreciable passivation for finite distances from the base steel; this distance was of the order of 2 inches only.

**Quality of Canned Orange Juice.** J. M. BOYD AND G. T. PETERSON, Continental Can Co., Inc., Ind. and Eng'g Chem. Ind. Ed., **37**, No. 4, 370 (1945) April.

In an investigation of factors af-

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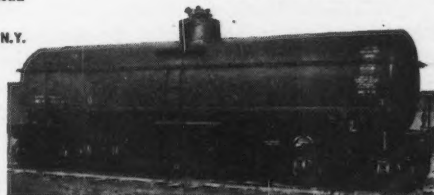
THE INTERNATIONAL NICKEL CO., INC., 67 Wall St., New York 5, N.Y.

PHENOL STORAGE TANK built by Whitlock Manufacturing Co., Hartford, Conn. of light gauge nickel sheet reinforced with steel. Nickel may be readily bent, shaped, forged or machined. It is easily welded, soldered or brazed.



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PROTECTING THE PURITY of phenol during transportation. This 8000-gallon nickel-clad steel tank car was built by American Car & Foundry Co. for a well-known chemical company.



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fecting the flavor of canned orange juice, it was found that plain tin cans cause some bleaching of color and impart a characteristic flavor, apparently due to the reducing action of the tin. The corrosion of the tin is, to some extent, dependent on the oxygen in the can. Use of enameled cans prevents loss of color and development of this flavor, but with a given oxygen content, more oxidation of the juice constituents occurs in enameled cans than in plain. Influence of oxygen on volatile oil, and heat treatment during sterilization and cooling, on flavor was studied. Length of heat treatment was more important than temperature.

**Corrosion Preventives.** C. M. LARSON, Sinclair Refining Co., Nat. Petr. News, **37**, No. 31, R-609 (1945) August 1.

Some 800,000 pieces of equipment will have to be coated with rust preventives and stored through the Reconstruction Finance Corp., and the Maritime Commission will have to rust-proof more than 2000 Liberty ships. Much of the storage will be in the open. The following tests for evaluating rust preventive materials are used: 1, humidity cabinet test; 2, salt spray test; 3, salt water immersion test; 4, hydrobromic acid neutralization test; 5, ultraviolet light test. Tables give the properties and procedures for application of rust preventives, with specification numbers.

**Corrosion - Inhibition - Protection.** J. A. HADREK, Paint, Oil Chem. Rev. **108**, No. 18, 9 (1945).

Corrosion processes and means of preventing them particularly by painting, are outlined. Pigments inhibiting corrosion are zinc yellow,

zinc chromate, zinc dust, red lead, blue lead, basic lead chrome and zinc oxide. Iron oxide, lithopone, venetian red, chrome yellow and magnesium silicate act as stimulators or inhibitors depending on their impurities.

**Developments in the Use of Lumnite Cement at Gary Works Coke Plant.** JAMES E. LUDBERG, Blast Furnace & Steel Plant **33**, 830 (1945) July.

Stacks carrying gases from waste heat flues operate at temperatures which permit dilute sulphuric acid condensate to form. Such condensate attacks mortar of the brick linings. In the production of ammonium sulphate, the sulphuric acid and the ammonium salt have a destructive action on concrete floors, walls, machine bases, as well as on structural steel supposedly protected by mortar made with regular cement. In all such cases mortars and concretes made with Lumnite (high alumina cement) have proven to be very corrosion resistant.

## GAS AND CONDENSATE CORROSION

**Corrosion Inhibitor Promises Huge Return.** KENNETH B. BARNES AND CHARLES T. DEEGAN, Oil & Gas J. **44**, No. 25, 84 (1945) October 27.

Discussion of work done by Stanolind Oil and Gas Co. Research Laboratories on mitigation of oil well sulfide corrosion by injecting small quantities of commercial grade formaldehyde into the annulus between the casing and the tubing. Based on the year previous to treatment, the number of pulling jobs was decreased 71 percent by the use of formaldehyde. The mechanism of



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protection is not known at this time. The estimated savings based on seven wells is 2900 percent.

**Tubing and Casing Corrosion Combated by Treated Water.** F. B. TAYLOR, *Oil and Gas J.* **43**, No. 47, 306 (1945) March 31.

Corrosion from water used in the water-driven fields of western Kansas is combated by a method involving use of stabilized water in the tubing-casing annulus, to prevent entry of formation fluids with their resultant corrosive action. The tubing-casing and annulus design is shown. The water injected is treated with sodium dichromate to inhibit corrosion, and is placed and held in the annulus by the use of a production packer on the tubing and an insert-type pump. A comparable method in use in salt-water-disposal wells utilizes crude oil instead of water in the annulus.

#### GENERAL CORROSION

**Prevention of Corrosion and Corrosion-Fatigue.** T. H. TURNER, *Instn. of Locom. Eng., Advance Copy*, May, 1945, 50 pp. *Nickel Bull.*, **18**, No. 6, 94 (1945) June.

The author, after brief reference to the essential nature of corrosion, describes a large number of typical examples of corrosion examined in the laboratories of the London and Northeastern Railway. These cover instances of corrosive attack suffered by railway rolling stock, railway electrical equipment, bridges, buildings, and ships and dock installations. A classification is made of the various forms of corrosion which may be encountered, and the terms commonly used in describing corrosion and its effects are listed. This review is followed by a survey of

the methods which may be employed for prevention of corrosive attack, viz, surface treatments and coatings, use of corrosion-resisting metals and alloys, treatment of water and cathodic protection. The principal types of coating and of corrosion-resisting materials are individually discussed and their respective spheres of usefulness are indicated. The inhibitory treatment of water is described. Reference is made to the work of organizations and individuals who have specialized in the study of various aspects of corrosion, and the paper closes with a plea for unremitting effort in the "war" against corrosion. A classified bibliography is appended to the paper.

#### FUNDAMENTALS

**Corrosion Inhibitors.** E. BOYE, *Chem. Zeit.* **67**, 302 (1943) *J. Inst. Metals & Metall. Abs.*, **12**, 185 (1945) June.

A review, with 94 references. The theory of action of such inhibitors and methods of testing their efficacy are discussed.

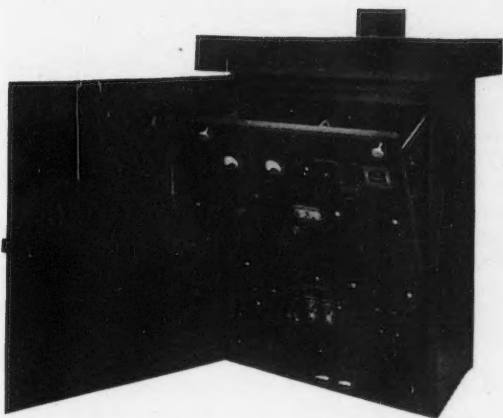
**On the Principles of the Formation of Metallic Coatings on Iron.** H. BABLIK, *Metallwirtschaft*, **21**, No. 27/28, 398, 1942 *J. Inst. Metals & Metall. Abs.*, **12**, 187 (1945) June.

The basic principles underlying the formation of metallic coatings are illustrated by reference to the galvanizing of iron. They are: 1, the number of intermediate layers is equal to the number of phases appearing in the equilibrium diagram of the two metals in question; 2, the relative thickness of the layers depends on the rate of diffusion through these layers; 3, columnar crystal growth results from the existing

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concentration gradients; 4, porosity of the coating is indirectly proportional to the reactivity between the two metals; and 5, the strength of the coating is lowest at the junction between the layers.

**Theory of the Corrosion of Metals—II—Further Study of Models of Micro-Elements.** V. S. DANIEL-BEK, *Zhur. Fiz. Khim.*, **18**, No. 5/6, 247 (1944) (in Russian) *J. Inst. Metals & Metall. Abs.*, **12**, 185 (1945) June.

Models of micro-elements having a ratio of anode area to cathode area less than 1 and models in neutral electrolytes were studied. The results obtained confirm the conclusions of a general character regarding fields of force in an electrolyte that were drawn from earlier work on models of micro-elements having equal anode and cathode areas and in acid electrolytes. New interpretations of the formulae of Muller and Akimov and Tomashov are advanced, based on ideas that are developed regarding the distribution of lines of equal potential and force in a circuit of micro-elements.

**Theory of the Corrosion of Metals in Solutions—III—On the Potential of Dissolving Metals—IV—On the Kinetics of the Solution of Metals.** A. I. SHULTIN, *Zhur. Fiz. Khim.*, **18**, No. 1/2, 61 (1944) (in Russian) *J. Inst. Metals & Metall. Abs.*, **12**, 185 (1945) June.

On the basis of the equations of the polarization curves, a calculation has been made of the potential of iron and nickel in solutions, assuming their surfaces to isopotential. The relationships obtained determine very well (qualitatively) the potential of the metal and its relation to the separate factors in the

system metal-solution. Equations for rate of solution of metals in dilute and concentrated solutions are derived. These equations take account of both the nature of the metal and the nature of the acid, and they represent a first qualitative approach to the description of the actual processes. The various experimentally observed kinetic laws of the solution of metals are extreme cases of the possible gradual transition from the one relation to another.

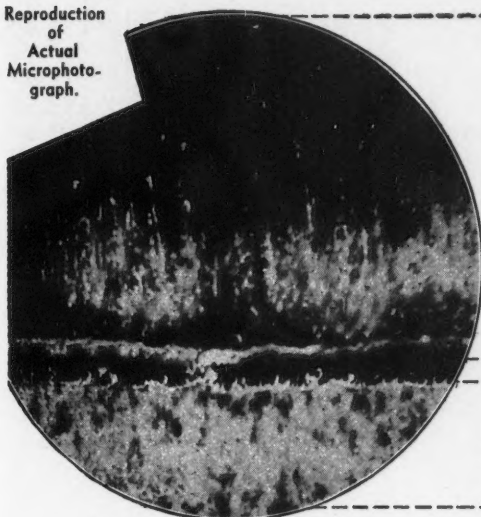
**The Film Theory of Passivity, the Protective-Etch Theory, and Phosphatization.** W. MACHU, *Z. Elektrochem.*, **48**, 619 (1942) *J. Inst. of Metals & Metall. Abs.*, **12**, 253 (1945) Aug.

Machu's theory of inhibition is not based on Muller's film theory of passivity, but is derived from separate experiments and line of thought. The objections of Weiner and Halla (in critical examination of Muller's theory, *Z. Elektrochem.* **48**, 1942, 361-377) to the pore-area method are based on incorrect assumptions as to the fundamental basis of this method. A review of experimental results obtained by the method shows them to be in agreement with those obtained by all other methods. The theory of passivity advanced by Weiner and Halla is unsupported.

**Discussion of Paper by W. Machu: Film Theory of Passivity, Protective-Etch Theory, and Phosphatization.** R. WEINER AND F. HALLA, *Z. Elektrochem.*, **49**, 135 (1943); *Chem. Zentr.*, **114**, No. 1, 1969 (1943); *J. Inst. of Metals & Metall. Abs.*, **12**, 253 (1945) Aug.

Cf. preceding abstract. Muller's

Reproduction  
of  
Actual  
Microphoto-  
graph.



A  
**ZINC**

B ZINC RICH ALLOY

C IRON RICH ALLOY

D IRON (STEEL) BASE METAL

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surface-relation law has found no independent experimental confirmation. The individual factors, viz., discrepancy of B value from that of the surface-relation formula, insufficient constancy of the A, B and C values, are emphasized. Reply by Machu.

**A Quantitative Study of the Corrosion of Pure Aluminum.** F. A. CHAMPION, *Trans. of the Faraday Soc.*, **41**, No. 283, 593 (1945).

The corrosion of pure aluminum specimens totally immersed in a horizontal position in normal potassium chloride solution was studied by periodical measurements of the hydrogen evolved and the oxygen absorbed. Typical corrosion-time curves are given and discussed. An equation is presented for rate of corrosion. Many features of these corrosion-time curves show a marked resemblance to those obtained for zinc under similar conditions. A platinum wire is used for burning hydrogen in the corrosion vessel.

**Behavior of a Separate Local Cathode Under Conditions of Oxygen Depolarization.** N. D. TOMASHOV, *Compt. rend. (Doklady) Acad. Sci. U. S. S. R.*, **27**, 983 (1940); *J. Inst. of Metals & Metall. Abs.*, **12**, 253 (1945) Aug.

On the assumption that the rate-controlling factor in the corrosion of a metal immersed in an aqueous solution is the diffusion of oxygen from the surface to the metal (the actual corrosion reactions  $\frac{1}{2}\text{O} + \frac{1}{2}\text{H}_2\text{O} \rightarrow \text{OH}$  being very rapid), a formula is deduced for the strength of the local current flowing as a result of the corrosion. From this it can be deduced that the c.d. at a

local cathode will rise rapidly as the edge of the electrode is approached; the relation between the mean c.d. will thus not be directly proportional to the area unless this is large, but will be greater, the smaller the area and the greater the perimeter/area ratio.

**Effect of Distribution and Dispersivity of Local Cathodes on the Rate of Corrosion Under Conditions of Oxygen Depolarization.** N. D. TOMASHOV, *Compt. rend. (Doklady) Acad. Sci. U. S. S. R.*, **27**, 987 (1940); *J. Inst. of Metals & Metall. Abs.*, **12**, 254 (1945) Aug.

Experimental support is presented for the conclusion that total current across a piece of corroding metal having cathodic inclusions will depend on their size and dispersion. A point is reached where the dispersion of the cathodic surface is so great that oxygen streams to the cathodic parts of the mosaic surface which no longer overlap, and the total current then remains constant.

**On the Hydrogen Overvoltage on a Lead Cathode in Concentrated Acid Solutions.** Z. IOFA, *Zhur. Fiz. Khim.*, **19**, No. 3, 117 (1945) (in Russian); *J. Inst. of Metals & Metall. Abs.*, **12**, 331 (1945) Oct.

The hydrogen overvoltage was measured on lead cathodes in hydrochloric (0.1-10N), hydrobromic (1-8.5N), perchloric (1-11.6N), and sulfuric acids (0.1-20N). The results given in the form of  $\gamma$ -log  $i$  curves show that: (a) the overvoltage decreases with increased acid concentration, this effect being less in the oxidizing acids, and (b) with the small c.d. ( $10^{-5}$  to  $10^{-7}$  am./sq. cm.), there is a sudden decrease in the



overtoltage. The first effect can be explained by an increased discharge of hydrogen, while the second effect is due to the presence of depolarizing agents.

**An Investigation of the Electrochemical Series from the Point of View of the Series Rules.** N. A. TANANAEV, Trudy Vsesoyuz. Konf. Anal. Khim., **2**, 297 (1943) (In Russian); J. Inst. of Metals & Metall. Abs., **12**, 222 (1945) July.

In order to study the accuracy of the general oxidation-reduction rule, the behavior of a series of metals when immersed in solutions of various metallic chlorides, sulphates, and nitrates was investigated. Certain of the metals were also studied in basic solutions. The results are given in the form of tables; these

include many exceptions to the general oxidation-reduction rule.

**Ionization of the Gas Space During the Corrosion of Amalgamated Aluminum.** B. A. KRASIUK AND V. A. KALININ, Compt. rend. (Doklady) Acad. Sci. U. S. S. R., **27**, 946 (1940); J. Inst. of Metals & Metall. Abs., **12**, 251 (1945) Aug.

By inserting amalgamated pure aluminum sheet and single aluminum crystals into an electrometer, it is found that corrosion is accompanied by an ionization of the (dry) ambient air to 10-100 times the normal residual value. The ionization is positive, and cannot be caused by mercury because introduction of mercury vapor into the chamber (containing only dry air) causes a reduction of the normal charge.

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Department of Chemical  
Engineering  
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**Kartinen, Ernest O.**  
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Bureau of Reclamation  
New Custom House  
**Gilliland, John L. Jr.**  
Bureau of Reclamation  
Customhouse

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NE.

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Corp.  
105 West Adams Street

**Goldsby, Fred L.**

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**Greve, Lyman F.**  
Commonwealth Edison Co.  
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2429 South Halsted Street

**McDonald, Hugh J.**  
Corrosion Res. Lab.  
Illinois Institute of  
Technology

3300 Federal Street  
**Shoan, Raymond A.**  
Dearborn Chemical  
Company

1029 West 35th Street  
**Starmann, George H.**  
2537 West Taylor Street

**Strothman, E. P.**  
A. O. Smith Corp.  
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Room 814

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Dept. of Metallurgical  
Eng'g.

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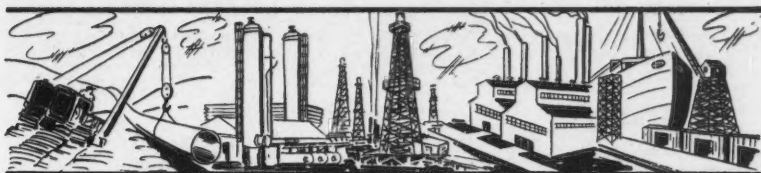
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